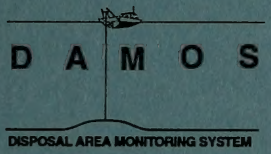
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An Investigation of the Dispersion of Sediments Resuspended by Dredging Operations in New Haven Harbor

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13. ABSTRACT

Maintenance dredging involving the removal of 840,000m³ from the New Haven Harbor main navigational channel took place between October 1993 and January 1994. Concern about the transport and fate of the resuspended sediments resulting from the dredging operations was expressed by the State of Connecticut's Department of Environmental Protection (DEP). The problem centered on the shallow water areas flanking the navigation channel which had been identified as winter flounder spawning grounds. An agreement was reached wherein field surveys, using an acoustic echo sounder, would be conducted while the dredge was operating. Additionally, a bottom-mounted instrument array, recording suspended sediment concentrations and other hydrographic parameters, would be deployed near the site of the flounder spawning grounds. This monitoring of the dredged sediment plume would provide a case history for future reference.

The two major objectives of the study were 1) establish what the background suspended sediment concentration is before and after dredging, and 2) document the movement of the dredge plume relative to fishery resource areas such as winter flounder spawning grounds.

The result of the acoustic surveys revealed that the dredge-induced sediment plume did protrude into the shoals area to the east and west of the main navigation channel. These excursions onto the shoals occurred only when the dredge was in the immediate vicinity. The DAISY, which was deployed on the eastern edge of the winter flounder spawning area, also showed elevated suspended material concentrations attributable to the dredge operating in the upper reaches of the harbor. The time series of the DAISY data showed numerous aperiodic short duration spikes of approximately 100 mg-1-1. The observed concentrations were an order of magnitude larger than the preceding background concentrations. However, in the last half of the deployment, while the dredge was located well south of the DAISY site, there were several long duration (1-3 days), very high concentration perturbations. During these events concentrations reached 700 mg -1-1 which could not be related to dredging operations. Evidence from the meteorological data and sewage effluent records indicate that these events are likely a result of winds and wind-generated waves, alone or in combination with, discharges from wastewater treatment plant outfalls.

Based on these findings, dredge induced sediment resuspension is a minor perturbation relative to the much longer duration, larger amplitude events associated with wind, wind-waves , and effluent discharges from outfalls . The effects of dredging related spikes in suspended sediment on the winter flounder spawning grounds, and the regional water quality in general appear limited in duration and of relatively low amplitude.

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EXECUTIVE SUMMARY

Maintenance dredging involving the removal of 840,000 yd^3 from the New Haven Harbor main navigational channel took place between October 1993 and January 1994. Concern about the transport and fate of the resuspended sediments resulting from the dredging operations was expressed by the State of Connecticut's Department of Environmental Protection (DEP). The problem centered on the shallow water areas flanking the navigation channel which had been identified as winter flounder spawning grounds. An agreement was reached wherein field surveys, using an acoustic echo sounder, would be conducted while the dredge was operating. Additionally, a bottom-mounted instrument array, recording suspended sediment concentrations and other hydrographic parameters, would be deployed near the site of the flounder spawning grounds. This monitoring of the dredged sediment plume would provide a case history for future reference.

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Based on these findings, dredge-induced sediment resuspension is a minor perturbation relative to the much longer duration, larger amplitude events associated with wind, wind waves, and effluent discharges from outfalls. The effects of dredging related spikes in suspended sediment on the winter flounder spawning grounds, and the regional water quality in general appear limited in duration and of relatively low amplitude.

1.0 INTRODUCTION

During the period October 2, 1993 through January 31, 1994, the U.S. Army Corps of Engineers, New England Division (NED), conducted maintenance dredging of the navigational channel in New Haven Harbor, Connecticut (Figure 1-1). This operation removed approximately 840,000 cubic yards of sediments which were then disposed at the Central Long Island Sound Disposal Site (CLIS). Prior to the initiation of this project, the State of Connecticut Department of Environmental Protection (DEP) expressed concerns regarding the potential dispersion of sediments resuspended by dredging and the deposition of these materials in areas defined as being "environmentally sensitive" because of their frequent use by flounder as a spawning area. These spawning grounds are located to the west of the federal navigational channel and to the north of the inner breakwater adjoining Sandy Point (Figure 1-1). Additional flounder spawning areas may be found at the southeastern limit of the harbor, within Morris Cove. In response to DEP concerns, the NED initiated a field investigation designed to monitor dredge-induced resuspension and to detail the area affected by the dispersion of these materials. This report provides a summary and discussion of the observations obtained as part of this investigation.

The major objectives for the field investigation of dredge-induced resuspension and the associated dispersion were defined as follows:

- To determine the normal background levels of suspended materials in New Haven Harbor immediately prior to and during the dredging of the federal navigational channel in the fall of 1993.

- To monitor the plume of materials suspended by dredging operations during flood and ebb tidal conditions to determine a) the spatial extent of the plume and b) its trajectory relative to the areas identified by the State of Connecticut Department of Environmental Protection as winter flounder spawning areas.

The study area lies within New Haven Harbor, Connecticut's largest port facility. Most of the tonnage entering the harbor is in the form of petroleum products, transported via tankers which use the 10.5 meter dredged navigation channel. Three tributaries feed into New Haven Harbor, the West River, the Mill River, and the Quinnipiac River. Both the West and Mill Rivers are small; the West River is only 3 km long and the Mill River's source, Whitney Lake, is less than 10 km from the harbor. The input from these two rivers can be considered negligible. Freshwater contributions from the Quinnipiac are also minor relative to the total flux of water in and out of the harbor (Richards 1988). The annual mean flow from the Quinnipiac gaging station in Wallingford, CT, for the period of record 1931 to

1994, is 6 $m^3 \cdot s^{-1}$. For comparison, the annual mean flow from the Connecticut River, the largest freshwater source to Long Island Sound, is 500 $m^3 \cdot s^{-1}$ (from 1928 to 1994). Natural depths within the harbor rarely exceed 4 meters. The navigation channel is flanked by broad shallows, most notably Shag Bank on the western side with a mean depth of 0.5 meters. Morris Cove, a large shallow embayment at the southeastern limit of the harbor, has a mean depth of approximately 3 meters, except for an abandoned borrow pit located near the middle of the cove, with a maximum depth of 11 meters.

2.0 METHODS AND PROCEDURES

2.1 Field Surveys and Water Sampling

A Raytheon Model DE719C® 200 kHz echo sounder was used for detecting the lateral and longitudinal extent of the suspended sediment plume. Transects were run cross-channel in an east-west orientation, with usually one transect up current of the dredge as a control, followed by several transects down current. A 1.7 liter Niskin bottle was used to collect water samples. On recovery, all water samples were stored in prerinsed plastic jars and returned to the laboratory for analysis. Concentrations of suspended sediment were determined by vacuum filtration through dried and preweighed Nucleopore® membrane filters (47 mm diameter, 0.40 micron pore size) mounted in standard Millipore® filtering apparatus. Navigation data were acquired using a Magnavox MX200® GPS Navigator with an MX-50R® Differential GPS Beacon Receiver attached to a notebook computer for continuous recording of ship position along each of the transect lines. A Seabird Electronics SBE-19 Seacat conductivity, temperature, and depth (CTD) probe was employed for obtaining hydrographic data, whenever possible during a survey, to assess the vertical structure of the water column.

2.2 DAISY Deployments

Concurrent with the above field operations, a single bottom-mounted instrument array, DAISY (Disposal Area In situ SYstem), was deployed to provide time series observations of hydrographic conditions and suspended material concentrations at a single point. The array was located immediately adjacent to the western edge of the navigational channel, along the eastern boundary of the winter flounder spawning area (Figure 1-1). Instruments mounted on the array included a single two-axis electromagnetic current meter, temperature and conductivity probes, two optical sensors to detail suspended material concentrations, and a datalogger for storing the data. The optical sensors were calibrated in the laboratory prior to deployment using sediments obtained from New Haven Harbor. All instruments were positioned to sample conditions at a point approximately 1 meter above the sediment-water interface. The logger was programmed to burst sample at a rate of 0.5 Hz for a period of one minute, average the burst, and store data, four times each hour. Data were recorded in digital binary format, stored in RAM, and downloaded during servicing to

a shipboard portable computer for subsequent analysis. A 20 foot Privateer, owned and operated by the University of Connecticut, was the boat used for all field surveys and array servicing.

3.0 RESULTS

3.1 Field Surveys

Of eleven field surveys attempted, nine were successful. One survey was abandoned due to inclement weather, and a second survey terminated due to mechanical difficulties on the dredge. The nine completed surveys, encompassing 65 transects, were conducted while Great Lakes Dredge #54 was operating in the interior reaches of New Haven Harbor. Reach limits, defined by Great Lakes Dredge and Dock, Co., are shown in Figure 3-1. Daily volumes of dredged sediment from the various reaches are plotted in a histogram (Figure 3-2). The barge used an open clamshell bucket with a capacity of 19.9 m^3. The surveys spanned the period from October 25 through November 18, 1993. Local weather and tidal conditions observed for each survey are summarized in Table 3-1, as well as the latitude and longitude of the barge location, and sampling activities. Dredge locations for all of the surveys are shown in Figure 3-3. The locations were determined by encircling the barge while running the GPS; if GPS was unavailable a symbol is used to denote the barge. A time series of the meteorological conditions, recorded at Norwalk Harbor by Northeast Utilities, during the dredging period is shown in Figure 3-4 and a summary in Figure 3-5. All of the echo sounder traces recorded are presented in Appendix A; plotted casts from the CTD are located in Appendix B.

The first survey took place on October 25; the dredge was located near the United Illuminating Company electric generating facility on the eastern side of the harbor (Figure 3-6). Echo sounder transects were run during the end of the ebb; tidal currents were slacking. The horizontal distribution of the dredge-induced sediment plume for this survey, and all subsequent surveys, is displayed as a heavy line on a transect (e.g., Figure 3-6, A) whenever material was present in the vertical. The resulting traces indicate that a plume is advected downstream within the confines of the channel for a distance of at least 250 meters (Figure 3-7). Throughout this survey the dredge was located near the United Illuminating outfall; thus, it is difficult to determine whether or not all of the echo sounder record is directly attributable to dredging operations (e.g., Figure 3-8). There is no indication of the plume, regardless of its source, migrating cross-channel to the bounding shallows along the western edge. Water samples collected near the United Illuminating outfall do show a significant decrease in the ambient salinity (Table 3-2). Specifically, samples #21 and #26 are 19.9 and 21.6 practical salinity units (psu), as compared to an average of approximately 26.5 psu for all surface water samples collected.

Two surveys were completed on November 2. A survey was run during maximum flood while the dredge was stationed south of the Gateway Marine Terminal (Figure 3-9) and another survey was conducted during the early ebb, after the barge moved north of the terminal (Figure 3-10). The flood survey indicated that the plume extended northward for approximately 400 meters. The United Illuminating outfall, located approximately 600 meters north of the barge, obscured the plume signal, and plume tracking in this region was terminated. A small patch of the plume was observed to the west of the main channel, in 6 meters of water, 400 meters north of the barge (Figure 3-11). The survey run during the beginning of the ebb shows that considerably smaller patches of the plume were advected along the channel for a distance of approximately 250 meters south of the barge (Figure 3-12). A small patch was observed 150 meters north of the barge, possibly a relict from the previous flood. Dredge operations stopped and started throughout the survey, which may explain the smaller, more variable nature of the patches. The CTD data, collected during the early ebb, shows only slight density stratification (2-3 psu) within the top 2 meters, due mainly to the proximity to upstream sources of fresher water, i.e., the Mill and Quinnipiac Rivers. Surface to bottom temperature differences were less than a degree.

The next day, November 3, the dredge was located in the vicinity of navigational buoy "17" (Figure 3-13). The survey was completed during the first two hours of the ebb; dredging was intermittent throughout the day. The plume trace was lost within 125 meters downstream (Figure 3-14). Results of this survey were difficult to interpret due to interference from wave turbulence; however, surface patches of black plume water were visually spotted (no evidence of plume traces on the echo sounder) within the navigation channel as far as 250 meters downstream. CTD data indicate a nearly vertically homogenous water column with temperature differences from surface to bottom of less than a degree and salinity differences of less than 2 psu.

The dredge was located near buoy "16" (Figure 3-15) during two ebb surveys conducted on November 11. Results of the first ebb survey, run during maximum ebb currents, indicated that the plume traveled approximately 525 meters downstream along the east bank of the channel (Figure 3-16) with excursions of 200 meters eastward onto the adjacent shoals. The second survey (Figure 3-17), during the latter half of the ebb, shows the plume again hugging the east bank for a distance of only 200 meters (Figures 3-18). Currents were slack by the end of the last transect. The majority of the plume observed during this second survey resides in deeper water with only minimal excursions (within 50 meters) over the adjoining shallows. Plume distributions in this area display some of the characteristics of a density current, i.e., a gravitationally induced density contrast between the sediment-laden plume and ambient waters (Figure 3-19). CTD casts, taken between the two surveys, indicate a well mixed water column with negligible stratification.

Only one survey near the end of the flood tide was attempted on November 15 due to deteriorating weather conditions (Figure 3-20). The barge was located to the west of Morris Cove on the eastern edge of the navigation channel. Patches of the plume were observed in the echo sounder record as far as 900 meters northeast of the barge, outside of the channel in Morris Cove (Figures 3-21). The plume protruded onto the shoals a maximum distance of 700 meters from the east edge of the channel. The CTD profiles show minimal vertical density stratification, indicating a homogenous water column. By the next day, November 16, the dredge had moved north about 300 meters, still along the eastern edge of the navigation channel (Figure 3-22). One survey was completed just before maximum ebb. Remnants of the plume were observed in Morris Cove, east of the channel, approximately 700 meters downstream of the barge (Figure 3-23). Plume traces were poorly defined and difficult to interpret during this survey. The CTD data, collected along the axis of the channel, show weak vertical and horizontal density gradients.

The final survey took place on November 18; the dredge was initially positioned near buoy "15" and proceeded slowly northward throughout the survey to a final position approximately 60 meters from its origin (Figure 3-24). One survey during maximum flood currents was conducted. The echo sounder record shows a patch of the plume in the channel nearly 600 meters upstream of the dredge barge (Figures 3-25). Small patches were detected outside of the channel, to the east and west, but generally only for short distances — within 100 meters. Plume definition throughout this survey was generally good. Again, the CTD profiles were obtained along the axis of the channel and indicate weak vertical, as well as horizontal, density gradients.

3.2 Water Sampling

During most of the plume surveys, water samples were collected to ascertain the relative amounts of suspended sediment with distance from the dredging operations. The results of this sampling are summarized in Table 3-2 and the location of each water sample relative to the barge is shown in the Figures 3-6, B; 3-9, B; 3-10, B; 3-13, B; 3-15, B; 3-17, B; 3-20, B; and 3-22, B. The highest concentration measured (662 $mg \cdot l^{-1}$) was located within 100 meters of the barge and associated with the near bottom waters. Indeed, most of the higher concentration data were within a 100 meter range of the barge, regardless of the tide stage. Beyond that distance, most of the data indicates that the concentrations within the dredge-induced plume were relatively low, decreasing rapidly under the combined effects of settling, advection, and turbulent diffusion and mixing.

3.3 DAISY Deployments

The bottom-mounted instrument array (DAISY) collected data from October 25 to December 7, 1993. The instruments on the array sampled conditions approximately one

meter above the bottom in water 4 meters deep. The DAISY was serviced once during the deployment period on November 11, 1993, at which point data were downloaded and sensors were examined for biofouling and cleaned by divers. The array was inadvertently moved from its original position of 41°17.008′ N, 72°54.973′ W and redeployed at 41°17.018′ N, 72°54.966′ W. This movement, of just 20 meters within water of the same depth, is considered insignificant for the purposes of this study, and the data are treated as if they were measured at one location. The resulting time series from the DAISY sensors for the entire deployment period is presented in Figure 3-26; A-E. A statistical summary of the hydrographic parameters (current velocity, temperature, and salinity) is presented in Table 3-3.

The area is characterized by relatively low energy with current speeds rarely exceeding 20 $cm \cdot s^{-1}$ (Figure 3-27; A); the overall mean velocity is 6.3 $cm \cdot s^{-1}$. There is a bidirectional tidal signal (Figure 3-27; B) although with a fair amount of spread about the principal axis, a result of the low current velocities. Using the methods of Mardia (1972), the mean direction on the ebb is 184° True and on the flood, 356° True. The average velocities are the same for both flood and ebb, although the ebb displays more variability and a higher maximum (Table 3-3). Energy spectra (Figure 3-28) show the north-south (along channel) component stronger in magnitude than the east-west (lateral) component and that most of the energy occurs at the semi-diurnal period of 12.42 hours (2 cycles per day). The data was of sufficient length, covering several spring-neap cycles, for determination of residual transport. Using a low pass filter with a 48-hour cutoff frequency, (Figure 3-29) the residual drift, at the DAISY site, is to the southwest with a velocity of 0.5 $cm \cdot s^{-1}$.

The time series of suspended material provided by the DAISY optical sensors indicate that background concentrations along the western margins of upper New Haven Harbor average approximately 8 $mg \cdot l^{-1}$. During a tidal cycle concentrations range 15 $mg \cdot l^{-1}$, peaking at about 25 $mg \cdot l^{-1}$. These values are consistent with the water samples obtained at sites throughout the study area prior to dredge operations, which suggests the suspended material field in New Haven Harbor is relatively homogeneous. The DAISY data show several aperiodic events resulting in concentrations approaching 100 $mg \cdot l^{-1}$ early in the deployment period and more than 700 $mg \cdot l^{-1}$ during the latter half of the deployment. The elevated concentrations observed on October 25 and then again on November 11 are the result of disturbances from positioning the DAISY array during deployment. The remaining perturbations may be the result of a variety of factors including the dredging operations, stream flow variations (indicative of rainfall events), winds and wind waves, and discharge from municipal sewage treatment facilities and CSOs. We explore the relative contribution of each of these parameters in the following paragraphs.

Throughout the first half of the DAISY deployment period, a series of short-term, or spiky, high concentration events occurred (Figure 3-30; A) sufficient to increase suspended

material concentrations from near average values to more than 100 $mg \cdot l^{-1}$. There appears to be no relationship between elevated concentrations and wind events (Figure 3-30; C and D), stream flow events (Figure 3-31; B), or municipal outflow data (Figure 3-31; C,D, and E). Wind speeds averaged only 5 $m \cdot s^{-1}$, and the mean river discharge is below average at 3 $m^3 \cdot s$ during this period. However, the dredge was operating in reaches 2, 3, 4, and 5 from October 25 to November 5 when the spikes are most obvious. After November 5, the barge moves outside of the entrance breakwaters to reach 8 (off the definition map in Figure 3-1) during which time the frequency of the spikes decreases dramatically. This suggests that the concentration spikes observed are most likely the result of intrusions of the dredge-induced sediment plume. The spikes are of short duration and tend to occur at times of maximum current velocity, evidence that the suspended material is being advected from a farfield source, as opposed to local resuspension which usually occurs just as tidal currents are increasing, or from sediment settling at slack water.

During the latter half of the DAISY deployment period (November 11 to December 7, 1993) several major events are recorded in the suspended material concentration data. These disturbances differ substantially in character from those that were observed during the first part of the deployment. In contrast to the short duration, spiky perturbations of the first deployment, the perturbations of the second deployment were longer lived and significantly larger in amplitude. These events also had a residual effect in that the average background concentrations increased to near 20 $mg \cdot l^{-1}$ (Figure 3-32; A).

The first sustained event, beginning on November 19, persisted for more than three days and increased concentrations to more than 700 $mg \cdot l^{-1}$. These concentrations exceed the maxima indicated by water samples taken in the vicinity of the operating dredge (Table 3-3). The dredge was working in Reach 5, 1 km south of the DAISY site. We believe this perturbation was not simply the result of dredge-induced resuspension. Even when the barge was operating much closer to the DAISY (Figures 3-6; A, 3-9; A, 3-10; A), resuspension events of this magnitude were not observed in the data (Figure 3-30; A). The dredge did move into Reach 2 on November 21, and may have contributed some amount of material to the final day of the event and possibly slowed the recovery of the system. Again, both the echo sounder and DAISY data indicate that the dredging process is incapable of producing such large amplitude and persistent perturbations at any site removed from the immediate dredging point. A more typical data record would show the sharp short-duration spikes in the suspended material concentrations (as seen in the first part of the deployment), not the long duration, high concentrations records observed here. There is no indication of increased stream flow (Figure 3-31; B) contributing to the suspended material field. However, effluent data from the nearby East Shore Water Pollution Abatement Facility (Figure 1-1) does show a significantly higher discharge of suspended solids (Figure 3-33; C) on November 19, a Friday, which could be the source material for the event. Records are not kept on weekends at the municipal facilities, and it may be that the higher than average effluent flow continued

over the next two days, Saturday and Sunday. An additional contributing factor to this event may have been the winds. Wind speeds during this time peaked at 10 $m \cdot s^{-1}$ out of the north for several hours (Figure 3-32; B). The fetch is sufficient and the winds strong enough to disturb the sediment-water interface at the water depths typical of this site. The wind, in combination with the increase in total effluent and suspended solids load from the sewage treatment facilities, appear to have been the principle factors producing this event.

After November 21 suspended material concentrations decreased from the maxima, although instantaneous values often exceeded 100 $mg \cdot l^{-1}$ resulting in average values significantly above the pre-perturbation levels. Included in this portion of the record are several short duration perturbations most probably caused by the inshore migration of materials resuspended by dredging in progress within Reach 2. Again, the majority of the perturbations during this period show characteristics different than those expected for dredge-induced perturbations. This may be the result of a residual effect from the previous three-day event, increasing the overall background concentrations.

On November 29 another large amplitude perturbation was observed, persisting for approximately 24 hours which does correlate with an increase in river discharge 3-5 times larger than the average flow. The salinity record shows a decrease of nearly 6 units on the practical salinity scale during the event (Figure 3-33; B). Records from the East Shore Water Pollution Abatement Facility (WPAF) do not indicate that there was a substantial contribution from this waste facility. However, there are 24 CSOs which discharge into upper New Haven Harbor; four of the largest ones are located south of the Tomlinson Bridge (Figure 1-1). Thus, although the data does not show significantly elevated effluent levels from the East Shore Facility, there may be a considerable contribution from the CSOs to the observed high concentrations. Potentially augmenting the increased river flow and CSO discharges, winds during the previous two days averaged above 10 $m \cdot s^{-1}$, and reached maximum speeds of 20 $m \cdot s^{-1}$ from the south. There is enough fetch to produce waves that would resuspend sediments at 4 meters depth, which then would have settled as the winds dropped and shifted to the north throughout the following day, possibly contributing to the high concentrations recorded. There is a similar event which occurred during the latter part of the day on November 30, again, possibly the result of stream flow 1.5 to 2 times higher than average, increased CSO input, and northerly winds.

The final and highest concentrations recorded during the entire deployment period spanned two days—December 2 and 3. No major stream flow events were recorded during this time. Winds were initially northerly but shifted to the east during the second day with speeds less than 10 $m \cdot s^{-1}$. There appears to be no significant contribution from the East Shore WPAF effluent. Although a northerly wind seems to have induced elevated suspended material concentrations in previous events, it is not likely that the winds produced the observed increase during this two-day period. A 700 $mg \cdot l^{-1}$ perturbation, persisting for

several days, represents a very large event, and winds would have needed to be much stronger and of longer duration. Other sources of suspended sediment sufficient to supply the mass needed to produce the large amplitude perturbations may be the additional regional outfalls and CSOs located throughout New Haven Harbor. Data sufficient to quantify the effects of these facilities on the regional suspended material field have been difficult to acquire. It seems reasonable, since all other contributions can be eliminated, that such sources may in fact dominate the observed events; however, the available data do not provide conclusive evidence.

4.0 DISCUSSION

The first objective of this field investigation on dredge-induced resuspension was to determine the normal background levels of suspended materials in New Haven Harbor immediately prior to and during the dredging of the navigation channel. The DAISY data indicate that, prior to dredging operations, background concentrations averaged 8 $mg \cdot l^{-1}$. After dredge operations began, short duration spikes on the order of 100 $mg \cdot l^{-1}$ were observed, but concentrations decreased to background fairly quickly. Only during the latter half of the deployment, when a number of environmental and anthropogenic factors combined, did the mass of sediment in suspension increase to a point where the background concentrations became consistently and considerably higher (20 $mg \cdot l^{-1}$).

The second objective was to monitor the plume of materials suspended by dredging operations to determine the spatial extent of the plume and its trajectory relative to the areas identified by the State of Connecticut Department of Environmental Protection as winter flounder spawning areas. The acoustic data obtained during the field surveys document that the sediment suspended by the dredging operations did, at times, migrate outside of the channel into the adjacent shoal areas. Excursions onto the shoals tended to occur during maximum tidal currents, and the plume was more likely to stay within the confines of the channel during early or late ebb tides. Unless the currents were at a maximum, the plumes became patchy, narrow, and difficult to identify within several hundred meters downstream. This is supported by the water sample data which show that concentrations drop fairly quickly away from dredging activity.

The CTD data indicate that there is a slight decrease in surface salinity at the head of the harbor, and water sample data do indicate considerable freshwater influence in the surface waters immediately adjacent to the municipal outfalls. Elsewhere, the water column is well mixed and vertically homogenous, with minimal salinity or temperature stratification. This suggests that the water column had a negligible effect on the observed vertical distribution of the plume material. Other confounding factors which can influence the horizontal and vertical distribution of the resuspended sediment plume are related to the physical and logistical characteristics of the barge operations. This includes bucket cycle time, bottom sweeping, number of passes at a particular location, and disposal barge

movement and overflow (Collins, 1995). This may partly explain the plume traces on the November 2 ebb survey which are small and patchy; the bucket cycle was aperiodic and intermittent throughout the surveying period.

The acoustic survey data also reveal that at the source of dredge operations the horizontal distribution of dredged sediments at the surface is extensive but tends to decrease with depth, i.e., conical in shape. This counters one of the more basic assumptions in most models of dredged sediment plumes, that of a homogenous vertical line source (e.g., . Christodoulou 1974, Schubel 1978, Wechsler and Cogley 1977, Collins 1995). Some of these models also assume a widening, or increasing horizontal distribution away from the source. The acoustic data exhibit progressively patchy and asymmetric distributions away from the dredging source. Additionally, in nearly all cases the traces showed that the shoreward, or shallow water, boundary of the plume in the areas immediately downstream are more well defined than the deep water margin within the navigational channel. This characteristic appears to be the result of gravitational flows driven by the density contrast between the sediment laden plume and ambient waters. This contrast decreases at the deep water plume edge; the combined effects of particulate settling, advection, and mixing cause the boundary to become more diffuse and difficult to define. Such spatial variability in the distribution of the plume sediment would seem to indicate that, unless models are able to reproduce these features, it can be expected that modeling results are overestimating the mass of sediment downstream and in areas receiving settling material.

The DAISY data also indicate several instances when suspended material resulting from proximate dredging activities intruded out of the channel and into the shoal areas, as evidenced by suspended material concentrations much larger than background. At the beginning of the deployment period these events were quite well defined and short lived. Resulting maxima seldom exceeded 100 $mg \cdot l^{-1}$. These events are similar to those previously observed during monitoring of dredge disposal operations within Long Island Sound (Bohlen et al. 1992) and are representative of the passage of relatively small portions of the suspended material plume. A majority of the spikes are occurring at times of maximum current, suggesting the material is advected from afar. If the site was a sink for the dredged sediment, spikes would occur at slack when material settled, and in the early stages of the tide, as the freshly deposited sediment would be easily resuspended.

During the latter part of the deployment, the data show several major perturbations in the suspended material concentrations persisting over nearly two days during which maxima approached 800 $mg \cdot l^{-1}$. Since for a significant portion of this time the dredge was operating well to the south of the DAISY site, the dredging operations cannot be identified as the principle source of these perturbations. Most of these larger events are clearly correlated with stream flow, wind stresses, and discharges from municipal outfalls and CSOs. However, the causes of the remaining events are not so obvious. There appears to be no

relationship with natural causes such as wind or rain storms. We can only speculate that there must have been other undocumented anthropogenic activities or discharges that may have perturbed the ambient concentration field.

5.0 CONCLUSIONS

The variety of data provided by DAISY and the echo sounder surveys indicate that dredging operations resulted in the transport of some amount of suspended material into the shoal areas flanking the navigational channel. At the DAISY site, this transport served to increase suspended material concentrations for a short period of time to maxima approaching 100 $mg \cdot l^{-1}$, an order of magnitude greater than ambient concentrations measured prior to dredging operations. The effects of these perturbations on regional water quality and/or benthic habitat must be evaluated relative to the effects of the larger amplitude, more persistent perturbations produced by the combination of wind waves and outfalls. The DAISY observations suggest that, against these latter factors, dredge-associated resuspension represents a smaller amplitude and shorter duration perturbation.

6.0 REFERENCES

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Table 3-1

Summary of Field Survey Activities and Environmental Conditions

Survey No.	Date	Dredge Location	Tide Stage	Spring/Neap	River Discharge $m^3 \cdot s^{-1}$	Water Samples	CTD Casts
1	October 25	41°17.133′ N 72°54.641′ W	Ebb, Slack before flood	Neap	2.6	SFC, BTM DAISY #12, 14, 16, 17, 19 #21, 25, 26	none
2	November 2	41°16.636′ N 72°54.693′ W	Flood	Spring	4.5	#1, 2, 3	#1, 2
3	November 2	41°17.684′ N 72°54.485′ W	Ebb	Spring	4.5	C7,C8, C9 C13, C14, C18	#4-17
4	November 3	41°16.759′ N 72°54.807′ W	Ebb	Spring	3.4	BTM DAISY, Buoy 18 SFC, BTM BARGE	#19-22
5	November 11	41°16.505′ N 72°54.653′ W	Ebb	Spring	2.6	BTM DAISY (2) SFC,BTM BARGE	none
6	November 11	41°16.505′ N 72°54.653′ W	Ebb	Spring	2.6	none	#23, 24, 25
7	November 15	41°15.515′ N 72°54.747′ W	Flood	Spring	2.6	none	#26, 27
8	November 16	41°15.720′ N 72°54.750′ W	Ebb	Spring	2.4	#40-44, Buoy 12	#28-33
9	November 18	41°16.205′ N 72°54.758′ W	Flood	Neap	4.8	#49, 53-56, N SCOW W SCOW, S DREDGE	#34-40

Table 3-2

Results of Water Sample Analysis

Survey Date	Station ID	Depth (meters)	SMC (mg/L)	Salinity (PSS)	Latitude 41 N (min)	Longitude 72 W (min)
25-OCT-93	DAISY	sfc	8.05	25.852	17.008	54.973
	DAISY	btm	11.30	26.401	17.008	54.973
	#12	1.2	36.72	26.862	16.995	54.588
	#14	1.8	85.40	26.801	17.009	54.598
	#16	1.8	57.02	26.844	16.985	54.602
	#17	1.8	10.14	26.172	16.990	54.802
	#19	1.8	31.20	26.289	16.975	54.588
	#21	sfc	16.06	19.922	16.927	54.587
	#25	1.8	46.88	26.288	17.023	54.581
	#26	sfc	10.90	21.570	17.029	54.496
02-NOV-93	#1	1.5	13.46	NA	16.755	54.551
	#2	6.1	14.15	26.708	16.775	54.690
	#3	3.7	14.14	26.558	16.794	54.801
	C7	3.0	10.46	26.430	17.745	54.346
	C8	1.2	16.62	26.072	17.658	54.407
	C9	4.6	39.82	26.533	17.650	54.463
	C13	6.7	26.08	26.793	17.607	54.584
	C14	1.5	32.96	26.336	17.596	54.512
	C18	3.0	11.40	26.476	17.555	54.708
03-NOV-93	DAISY	btm	6.32	26.815	17.014	54.966
	Barge1	3.0	23.34	26.828	16.762	54.763
	Barge2	sfc	30.36	26.740	16.767	54.764
	Bouy #18	btm	12.25	27.392	16.767	54.676
11-NOV-93	DAISY #1	btm	8.84	26.830	17.014	54.966
	DAISY #2	btm	22.38	26.459	17.014	54.966
	Barge 1	sfc	44.04	26.710	16.427	54.605
	Barge 1	btm	662.12	NA	16.426	54.613
16-NOV-93	#40	3.7	9.88	27.071	15.775	54.714
	#41	3.7	57.6	26.979	15.685	54.740
	#42	3.7	41.6	26.964	15.593	54.759
	#43	3.7	17.97	27.171	15.432	54.793
	#44	3.7	9.42	27.289	15.321	54.839
	Bouy #12	3.7	7.18	27.257	15.279	54.801
18-NOV-93	#49	4.3	8.02	26.736	16.279	54.731
	#53	4.3	8.26	26.711	16.315	54.731
	#54	4.3	8.76	26.604	16.401	54.727
	#55	4.3	8.28	26.546	16.462	54.727
	#56	4.0	8.78	NA	16.519	54.732
	N of Scow	4.3	14.98	26.656	16.238	54.762
	W of Scow	sfc	575.02	26.665	16.200	54.760
	S of Dredge	4.3	7.26	26.950	16.167	54.754

Table 3-3

Statistical Summary of Current Meter and Hydrographic Data from DAISY

	velocity (cm/s)	flood (cm/s)	ebb (cm/s)	LPF north (cm/s)	LPF east (cm/s)	temp #1 (degC)	temp #2 (degC)	salinity (PSS)
mean	6.26	6.26	6.28	-0.30	-0.42	10.31	10.29	24.82
std	3.33	3.12	3.52	1.19	2.56	1.68	1.68	0.68
min	0.26	0.26	0.27	-3.19	-6.01	7.20	7.22	19.09
max	34.31	21.40	34.31	1.97	3.52	15.01	14.91	25.98

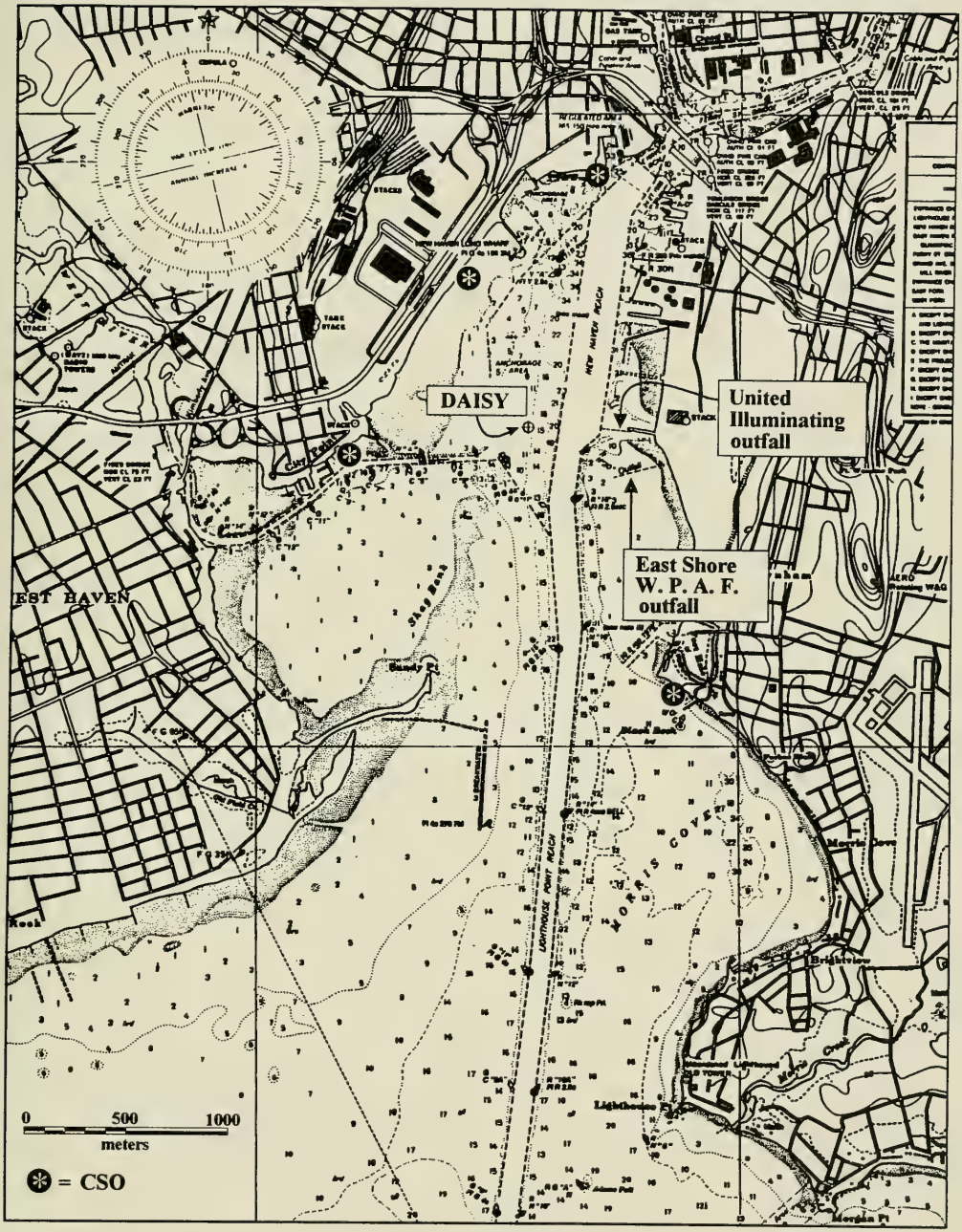


Figure 1-1. Bathymetric chart of the study area, New Haven Harbor, CT (from NOAA Nautical Chart #12371 - Scale 1:12, 800)

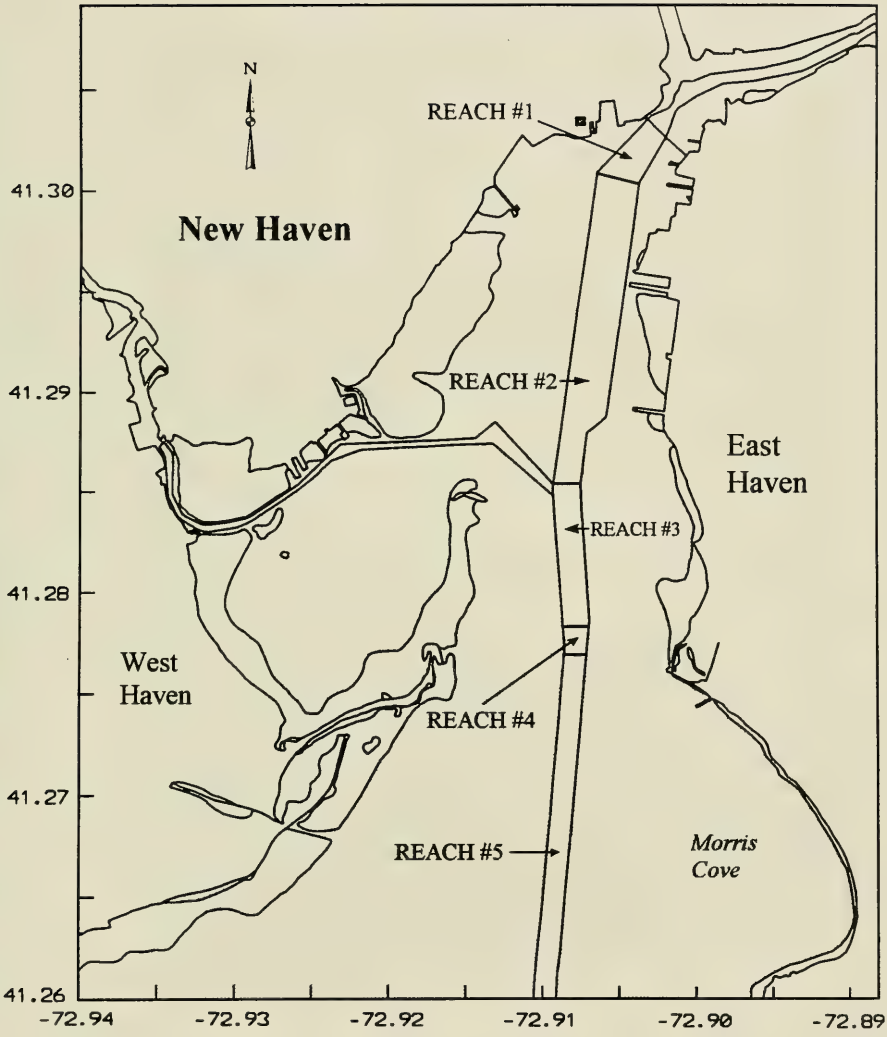


Figure 3-1. Great Lakes Dredge and Dock Company's reach definitions, New Haven Harbor



Figure 3-2. Sediment volume dredged per day from October 2 to December 3, 1993

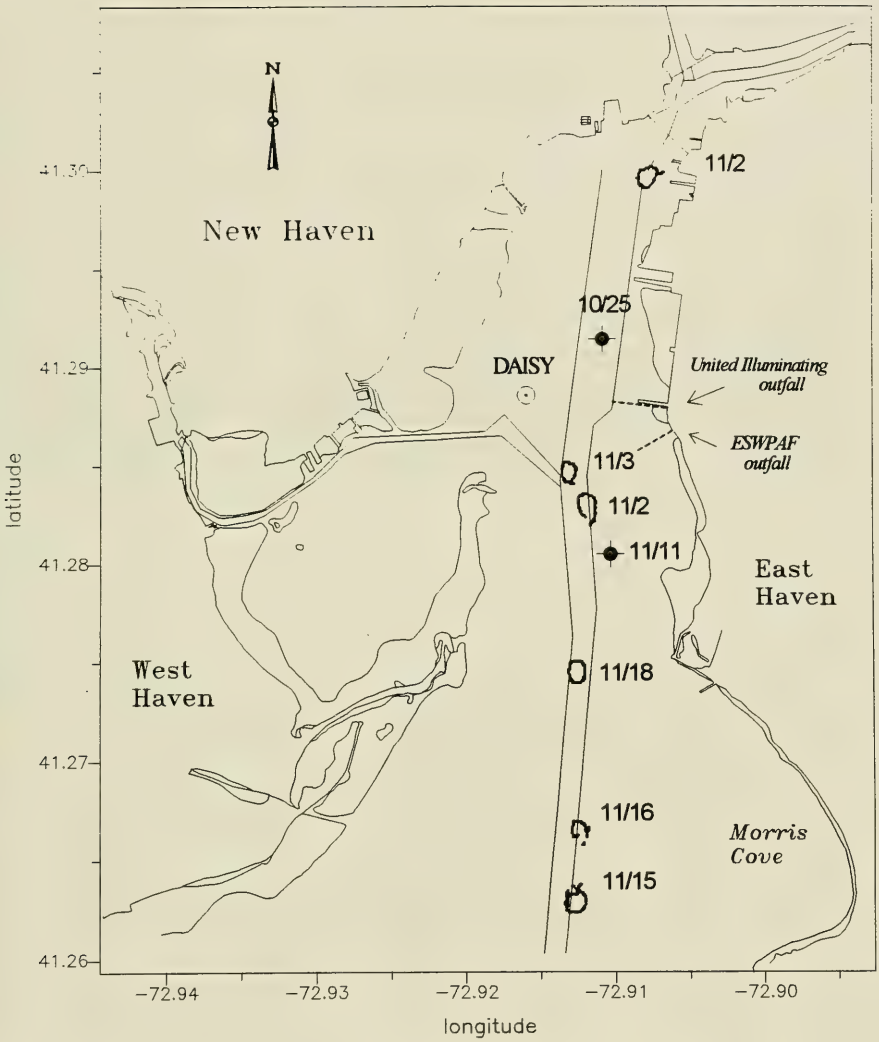


Figure 3-3. Location of the dredge barge during each field survey

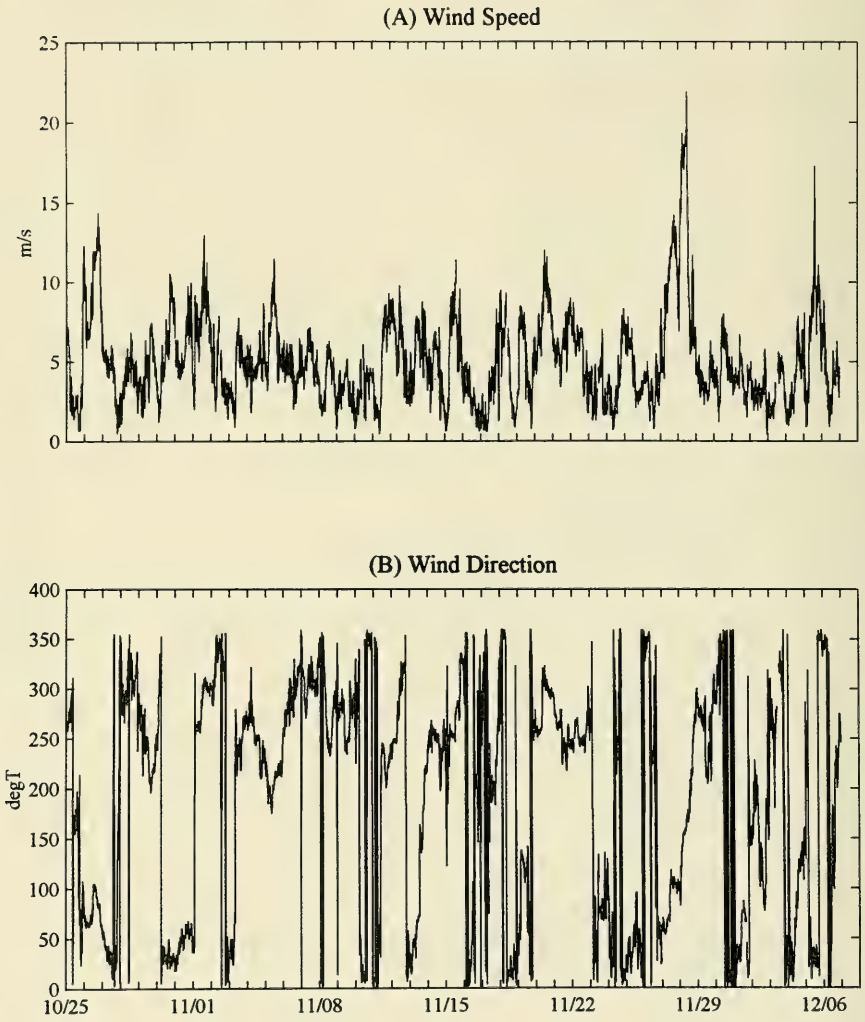


Figure 3-4. Meteorological data obtained from the Northeast Utilities Norwalk Harbor station: (A) wind speed, and (B) wind direction, measured at 10 meters above ground level

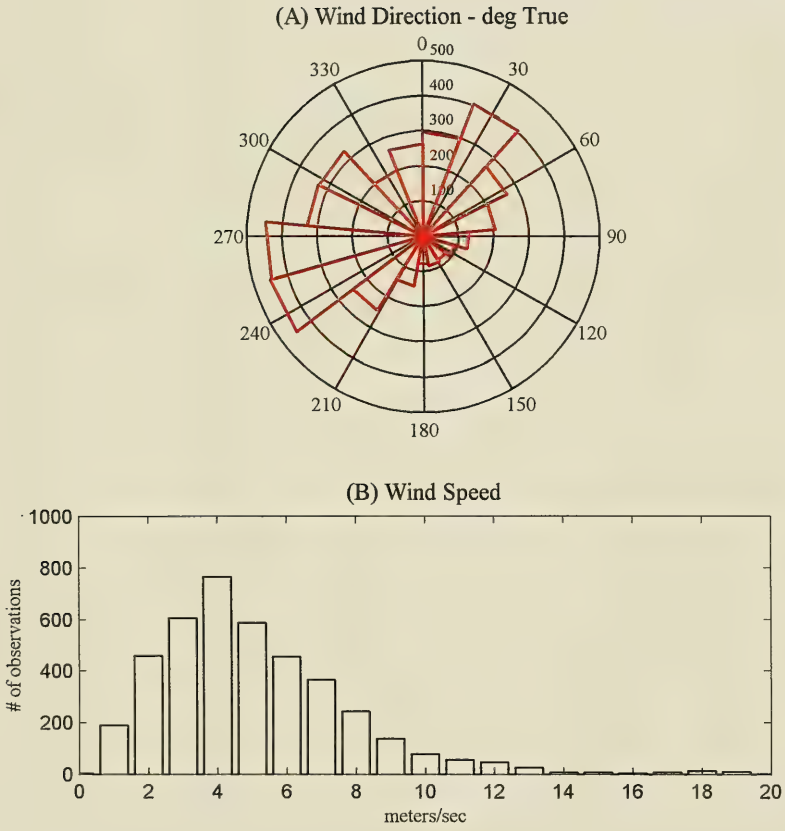


Figure 3-5. Summary plots of the meteorological data: (A) rose histogram for wind direction (plotted as the direction from which it comes), and (B) wind speed histogram

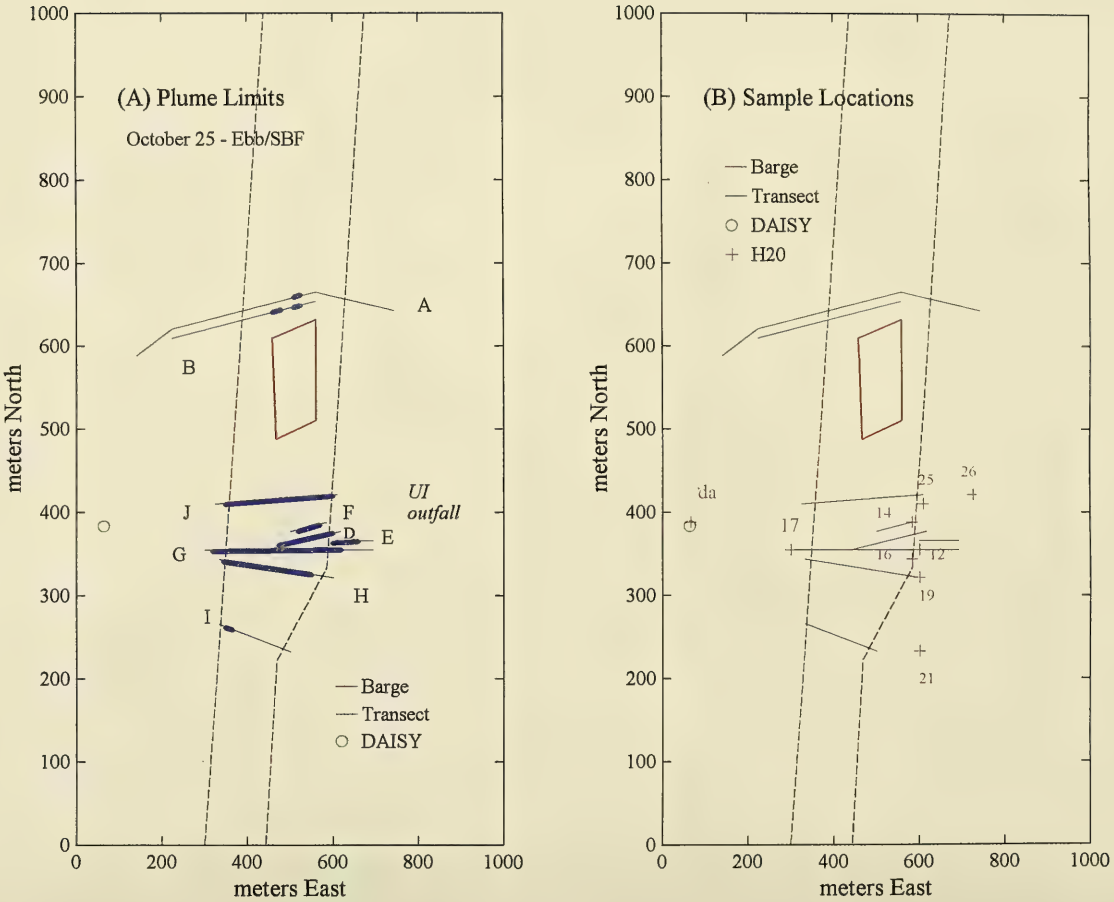


Figure 3-6. (A) October 25, 1993 barge position and transect locations with the occurrence of the plume delineated on each transect; (B) barge position and transects with the location of water samples

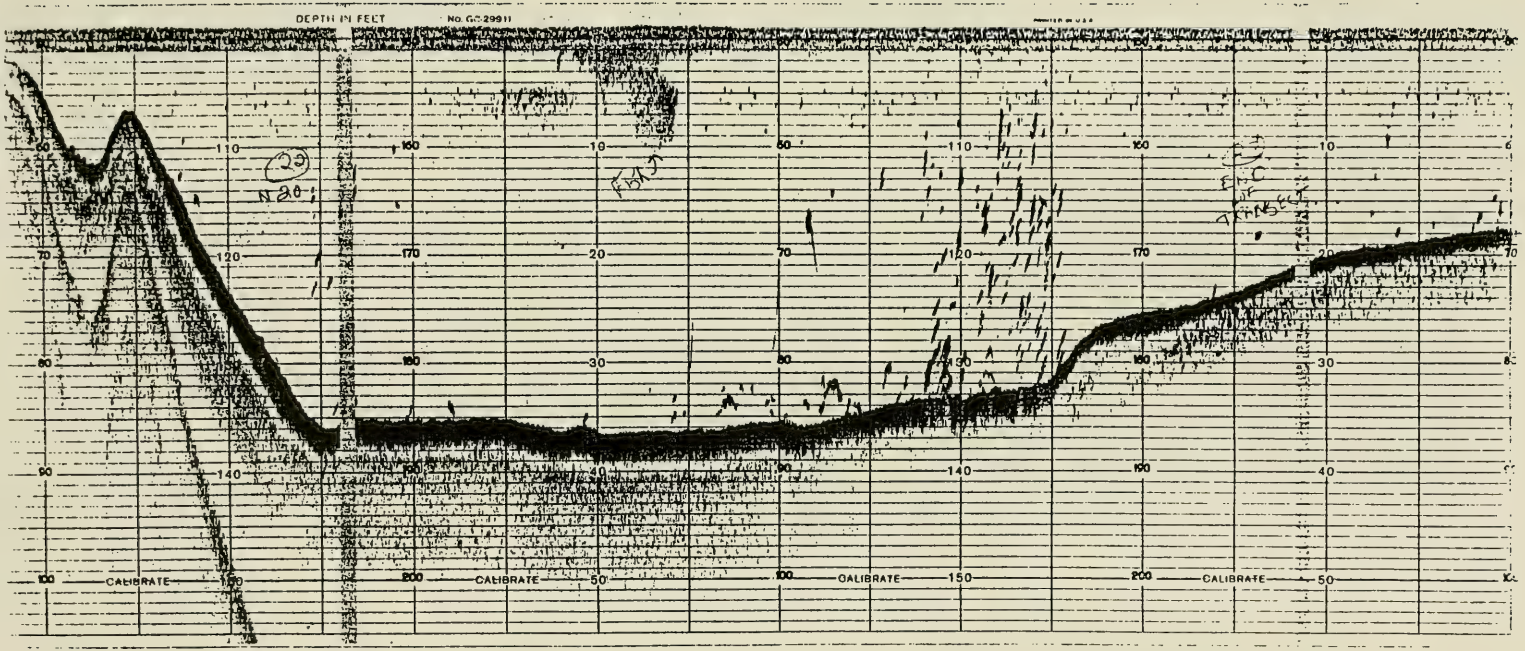


Figure 3-7. Echo sounder trace of Transect I showing patches of plume 250 meters downstream of the barge on October 25. The profile runs east to west.

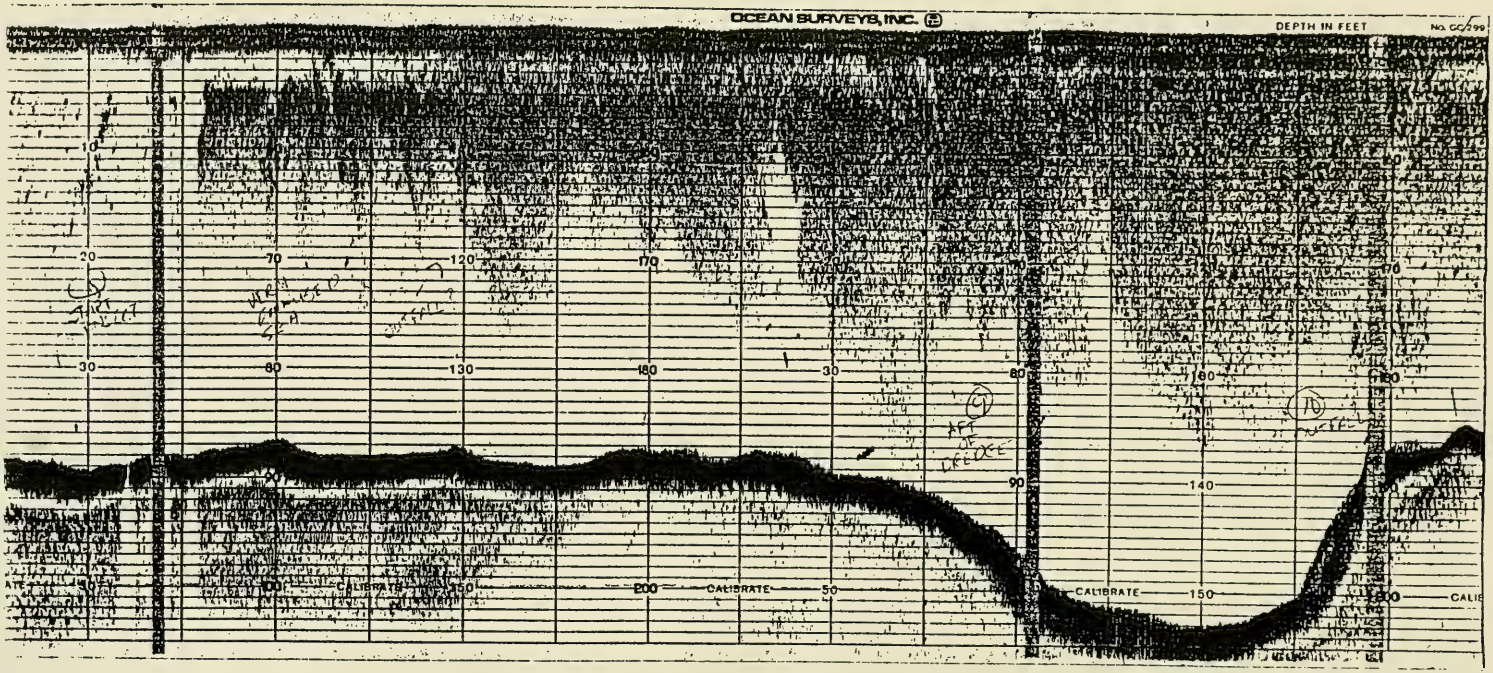


Figure 3-8. Echo sounder trace near the United Illuminating outfall, October 25. Profile runs west to east.

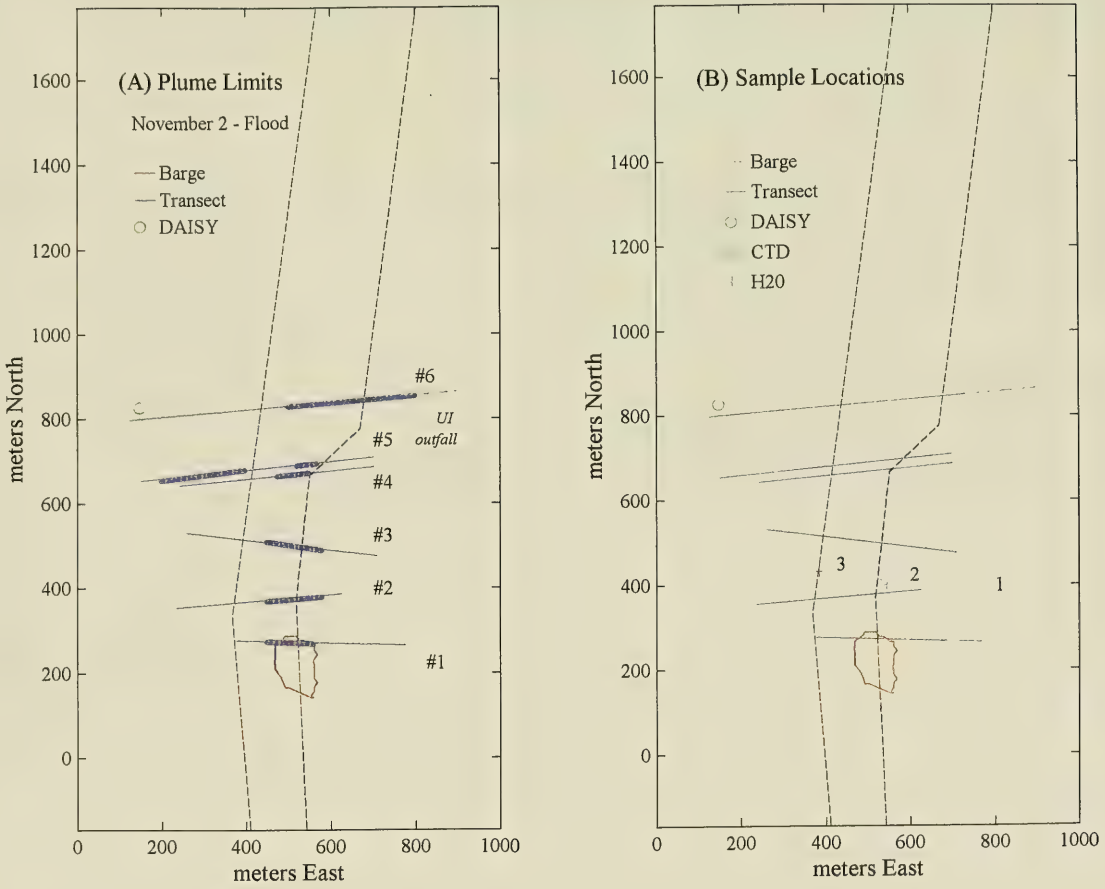


Figure 3-9. (A) November 2, 1993 (flood) barge position and transect locations with the occurrence of the plume delineated on each transect; (B) barge position and transects with the location of water and CTD samples

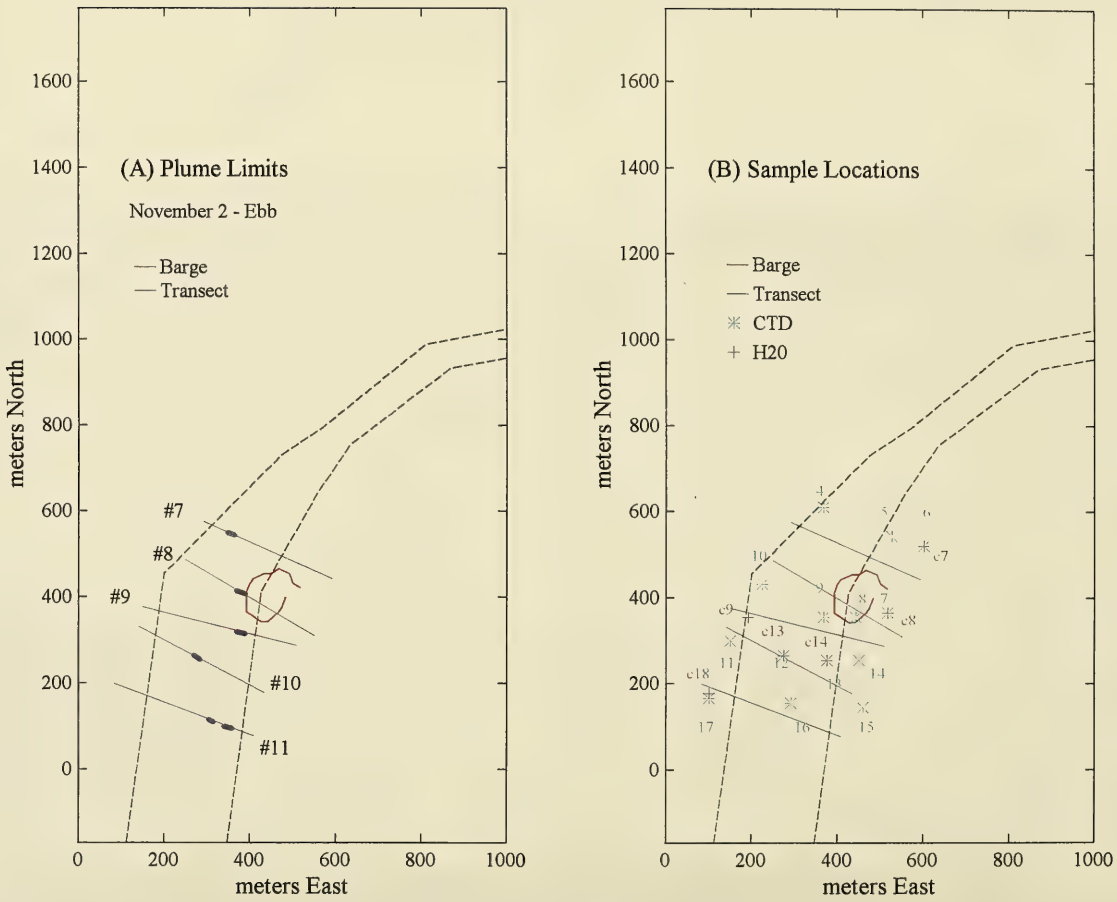


Figure 3-10. (A) November 2, 1993 (ebb) barge position and transect locations with the occurrence of the plume delineated on each transect; (B) barge position and transects with the location of water and CTD samples

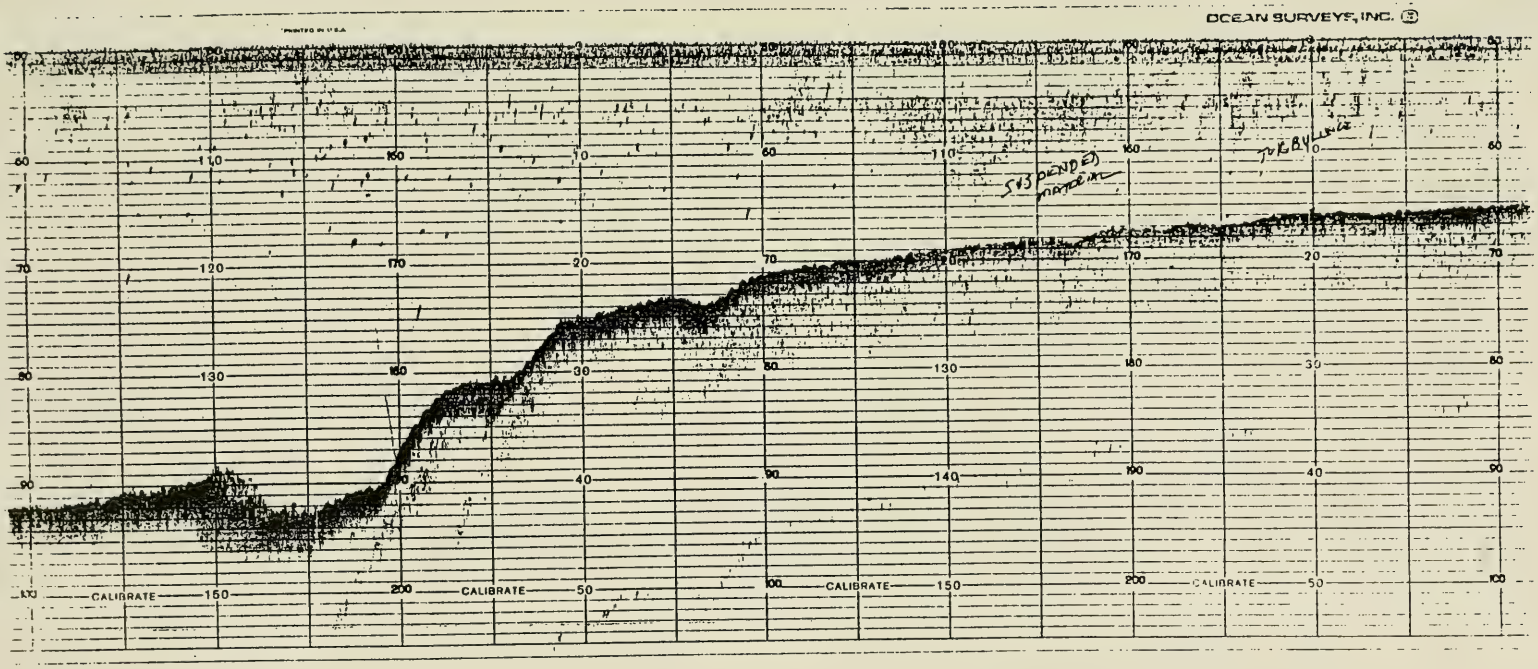


Figure 3-11. Patch of the plume observed while running Transect #5, 400 meters downcurrent and out of navigation channel, November 2. Profile runs east to west.

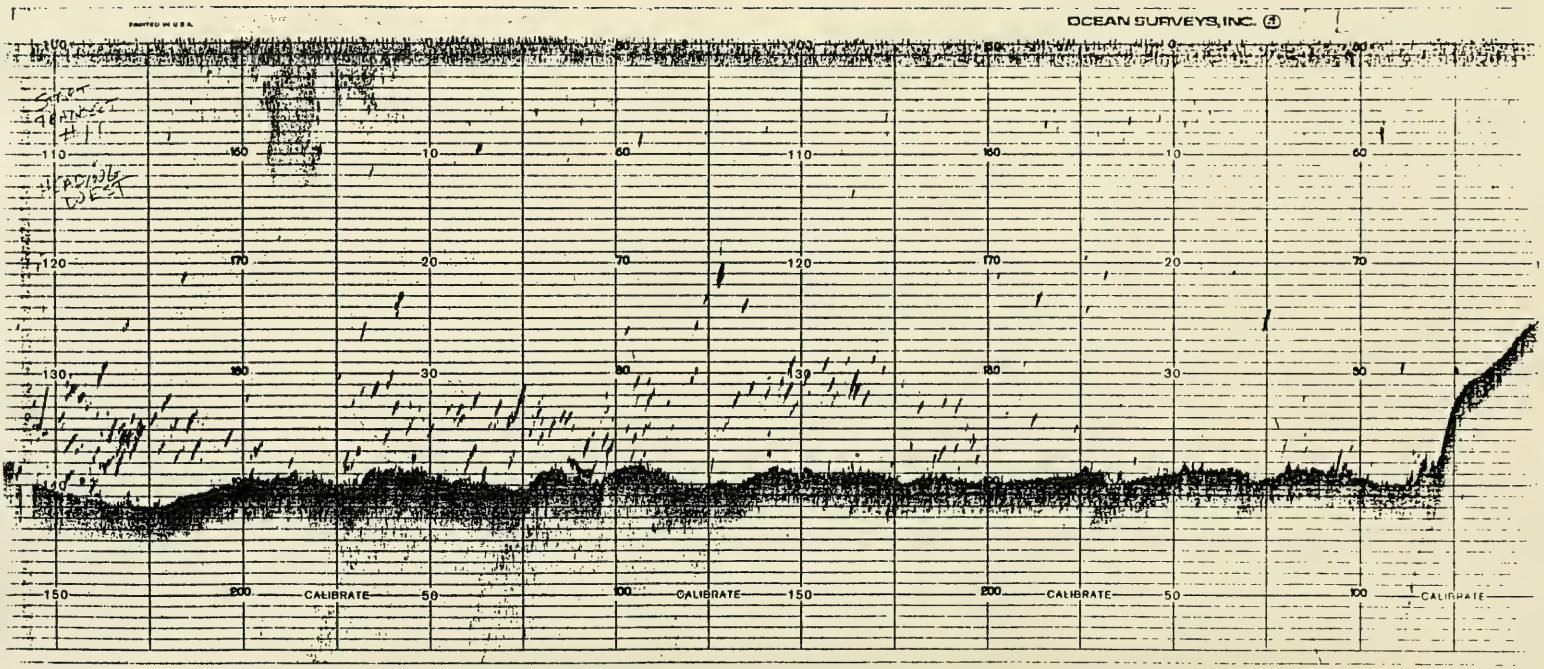


Figure 3-12. Transect #11, showing a plume patch that has been advected 250 meters downcurrent along the eastern side of the navigation channel. Profile runs east to west.

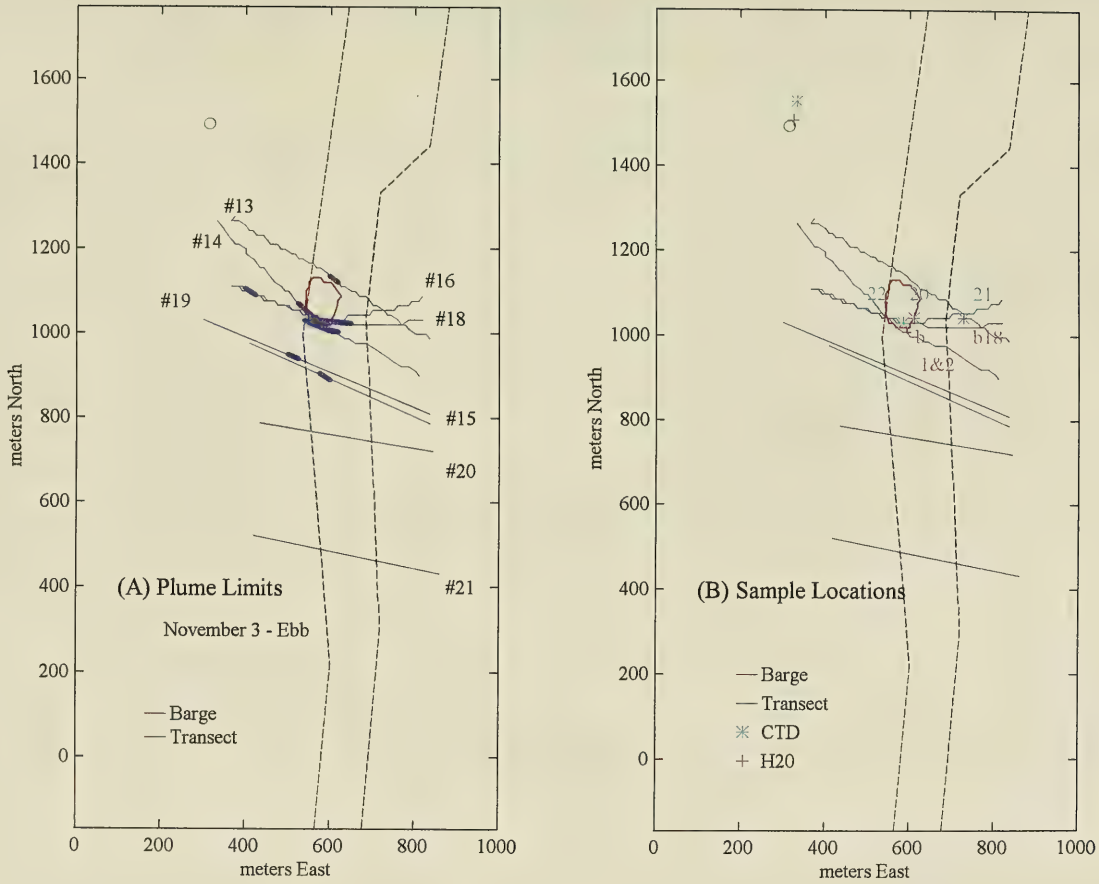


Figure 3-13. (A) November 3, 1993 barge position and transect locations with the occurrence of the plume delineated on each transect; (B) barge position and transects with the location of water and CTD samples

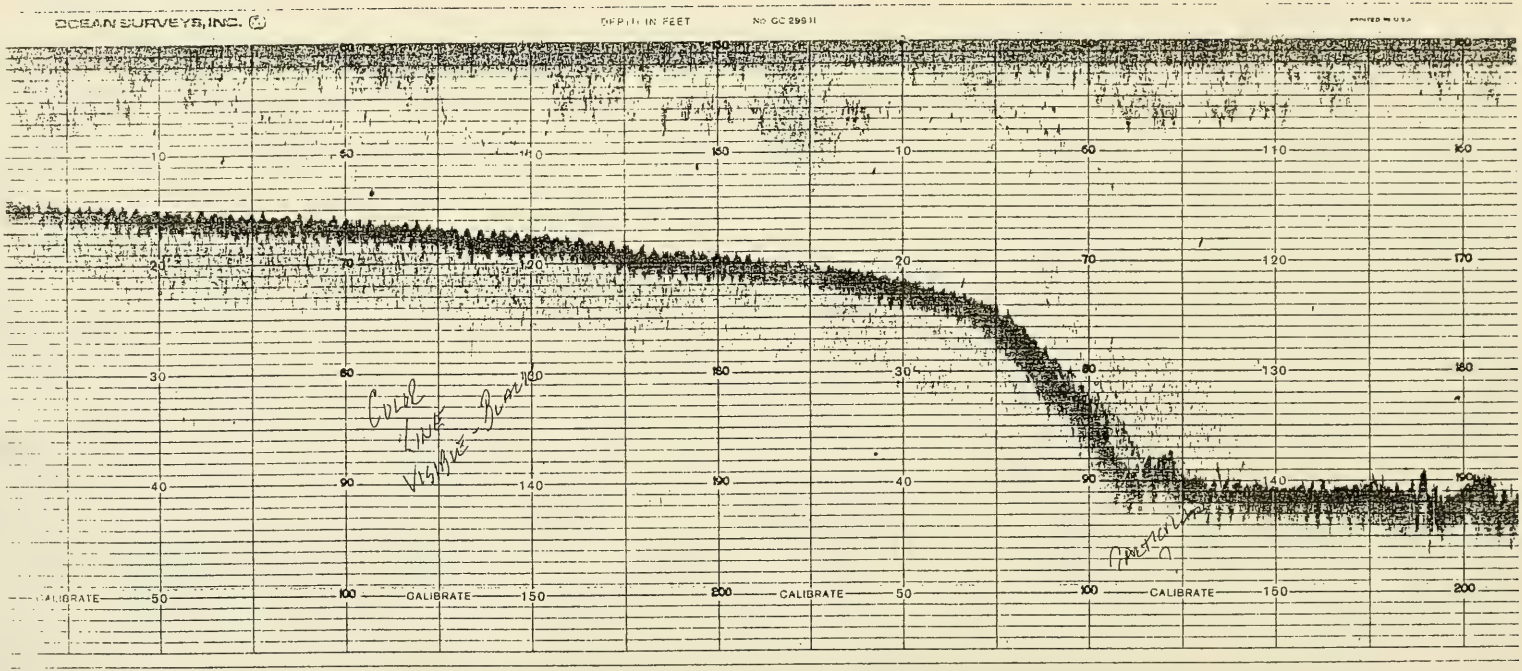


Figure 3-14. Dark patches of the plume detectable in the echo sounder trace of Transect #19, 125 meters downcurrent of the barge on November 3. Profile runs east to west.

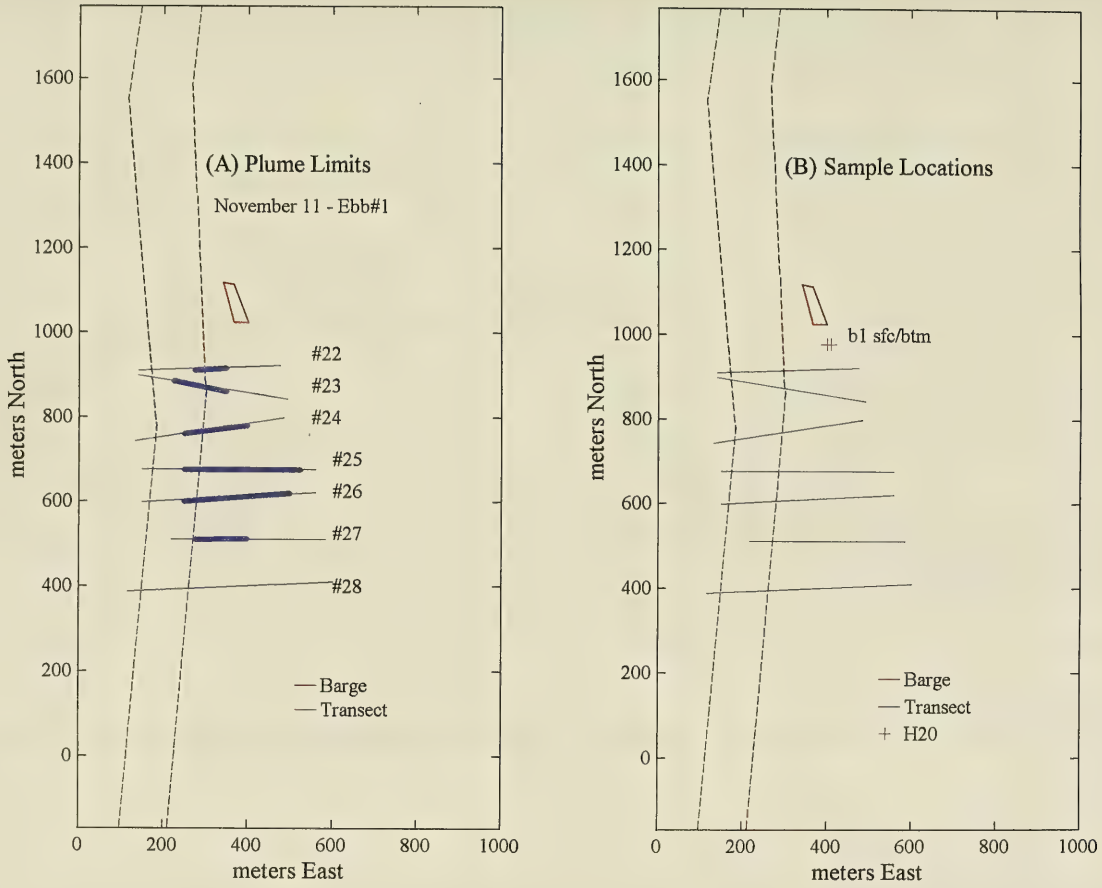


Figure 3-15. (A) November 11, 1993 (first ebb survey) barge position and transect locations with the occurrence of the plume delineated on each transect; (B) barge position and transects with the location of water samples

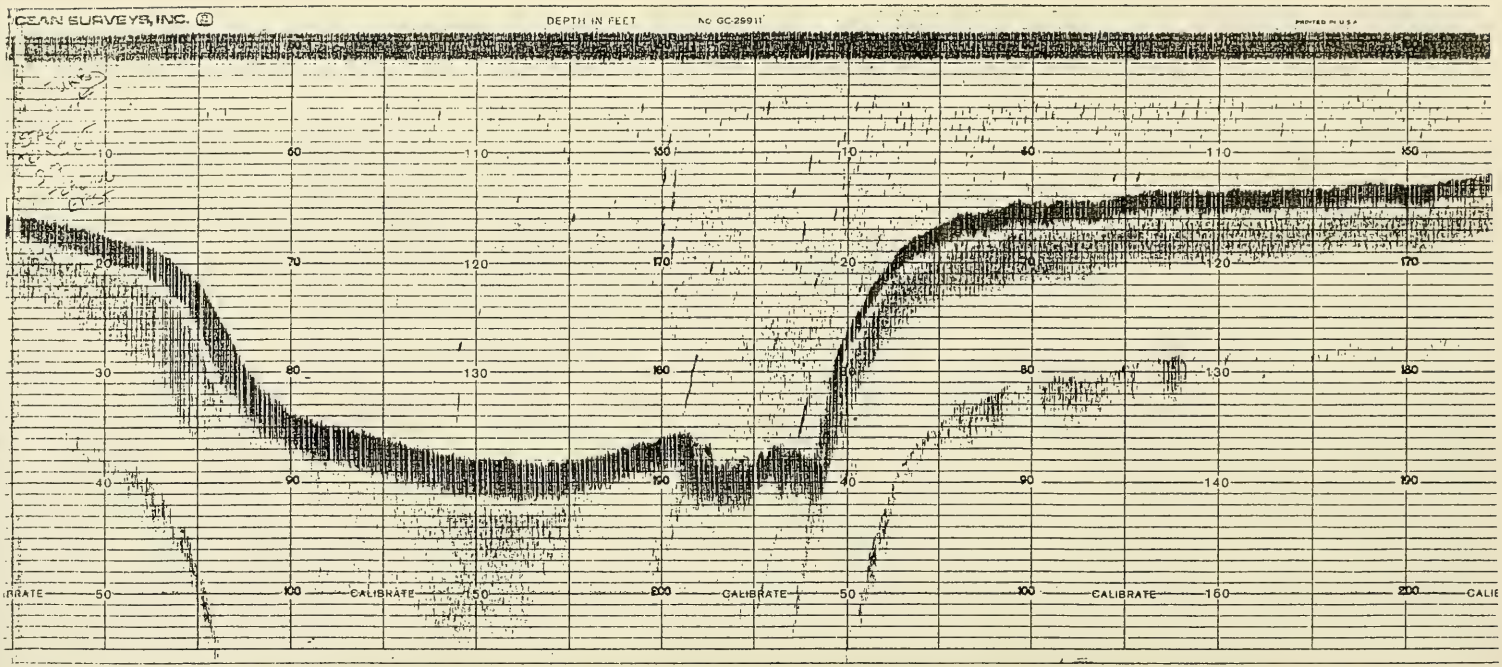


Figure 3-16. Traces of the plume from the echo sounder records of Transect #27, advected 525 meters downcurrent along the eastern boundary of the channel, November 11. Profile runs west to east.

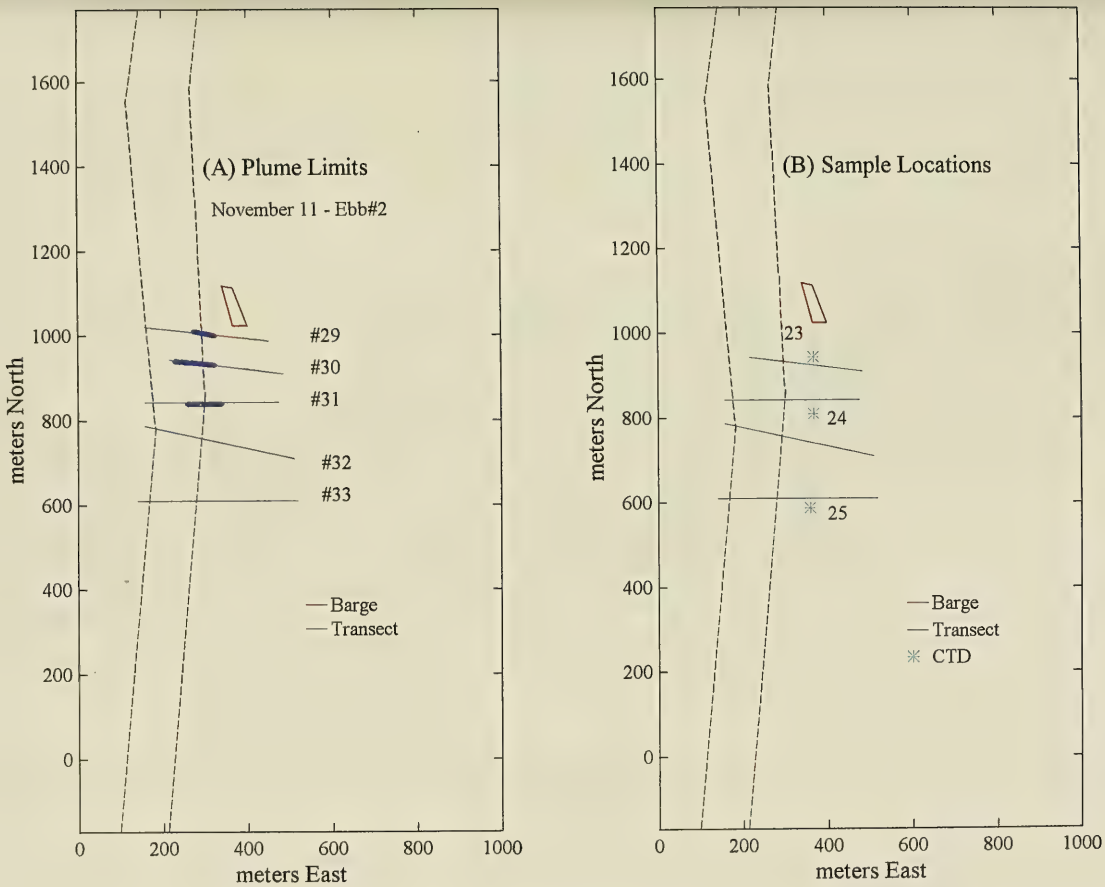


Figure 3-17. (A) November 11, 1993 (second ebb survey) barge position and transect locations with the occurrence of the plume delineated on each transect; (B) barge position and transects with the location of water samples

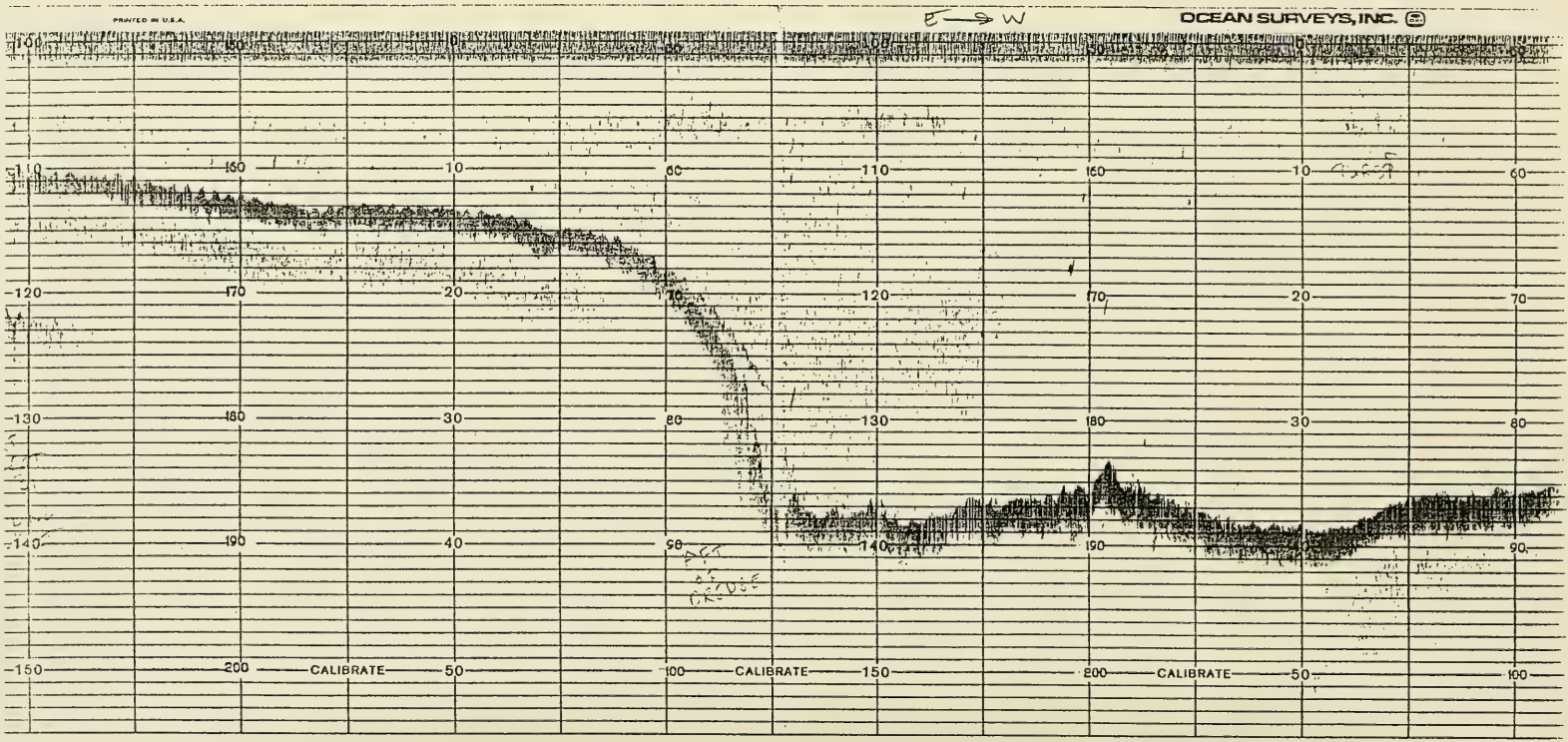


Figure 3-18. Echo sounder record from Transect #31; portions of the plume have been advected 200 meters downstream along the eastern flanks of the channel, November 11. Profile runs east to west.

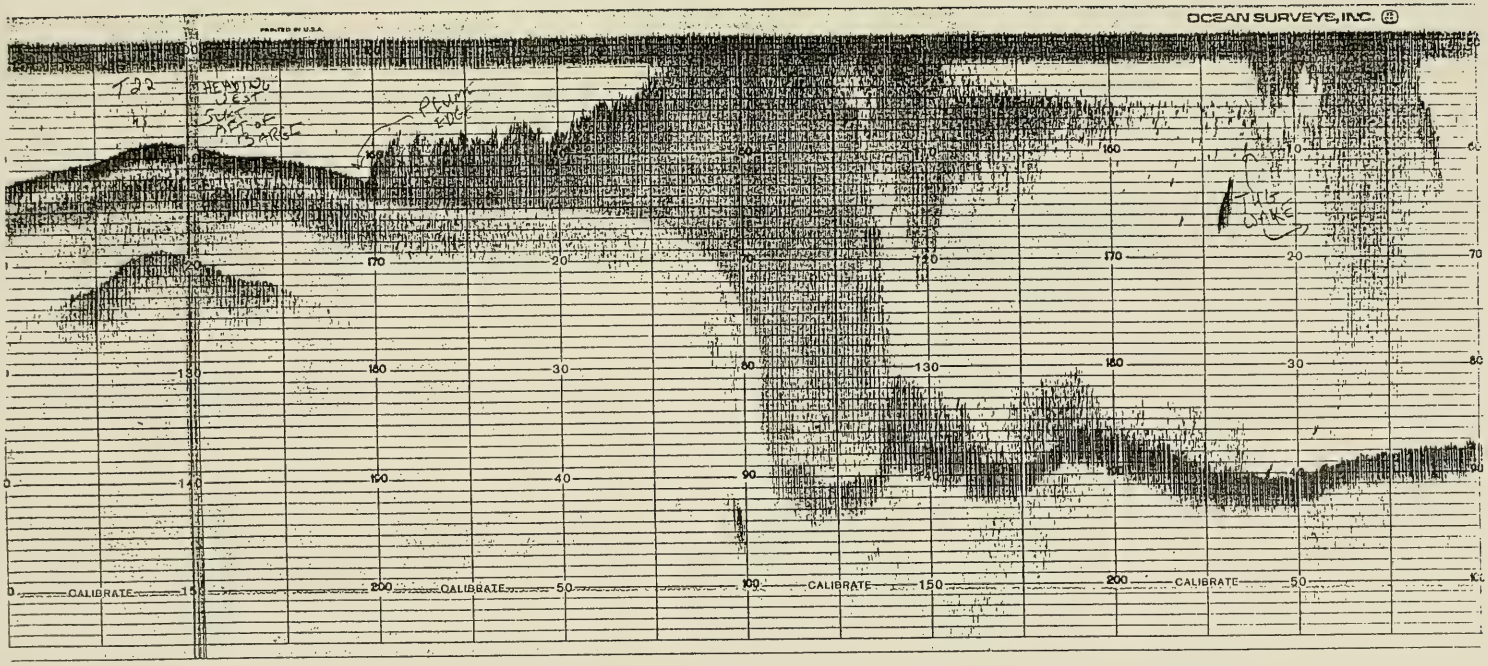


Figure 3-19. Echo sounder trace from Transect #22, just aft of the barge on November 11, showing an example of the dredged sediment plume with characteristics of a density current. Profile runs east to west.

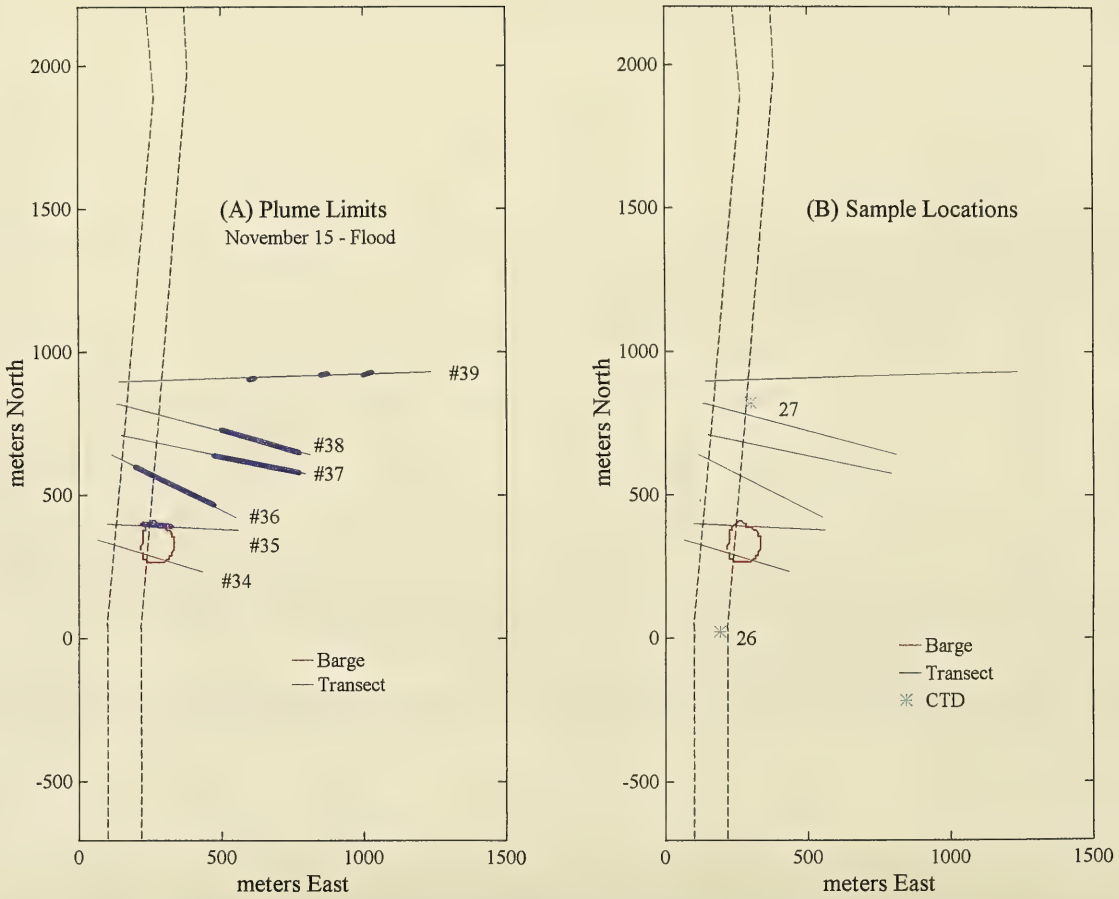


Figure 3-20. (A) November 15, 1993 barge position and transect locations with the occurrence of the plume delineated on each transect; (B) barge position and transects with the location of water samples

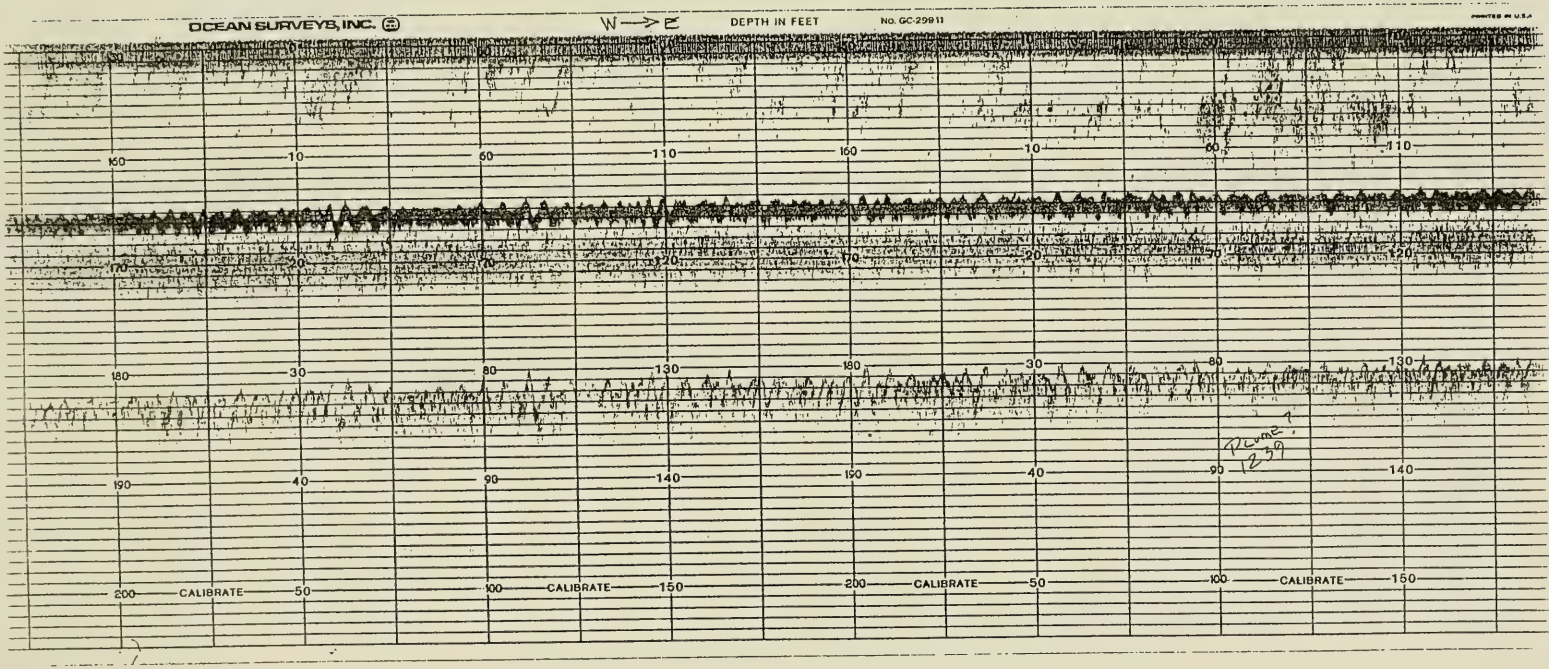


Figure 3-21. Patches of the plume observed in the shoal areas of Morris Cove, 650 meters northeast of barge operations. Profile is from Transect #39 recorded on November 15, and runs west to east.

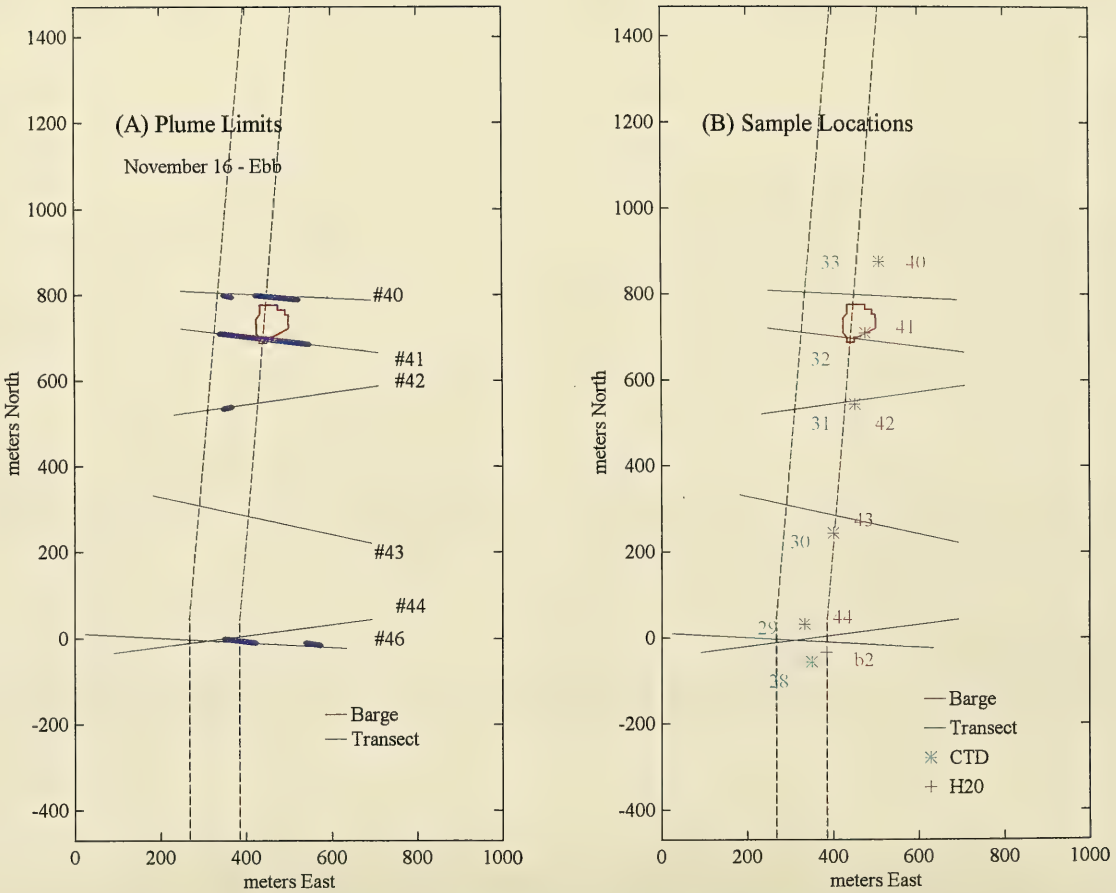


Figure 3-22. (A) November 16, 1993 barge position and transect locations with the occurrence of the plume delineated on each transect; (B) barge position and transects with the location of water samples

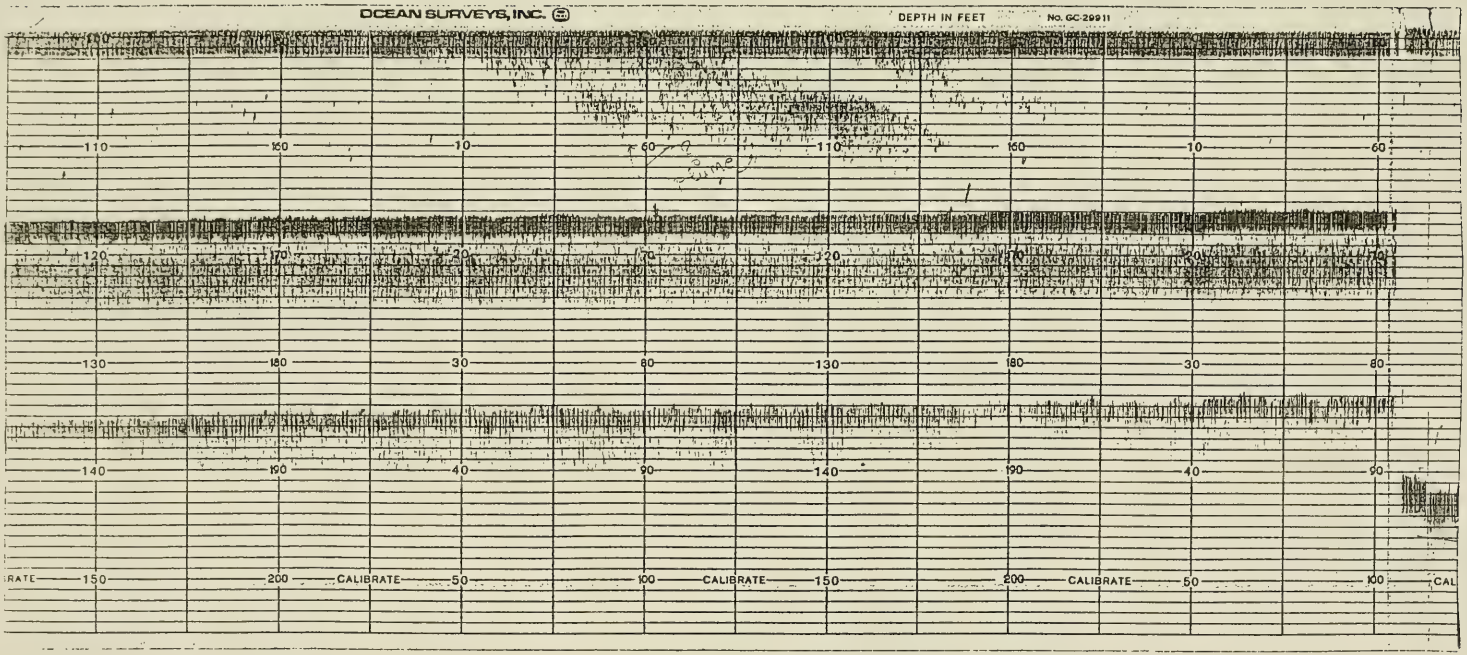


Figure 3-23. Patches of the plume observed outside of the navigation channel, in Morris Cove, 700 meters downcurrent of the barge. Profile is from Transect #46 recorded on November 16, and runs west to east.

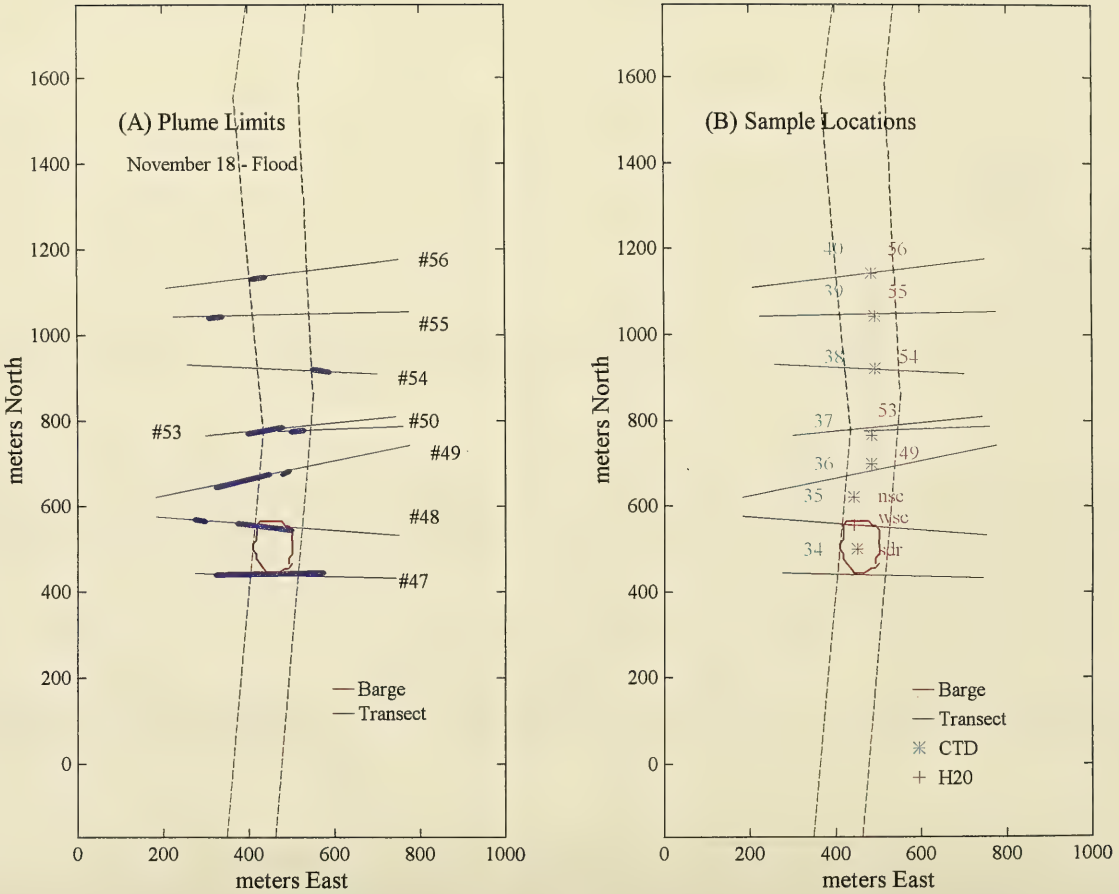


Figure 3-24. (A) November 18, 1993 barge position and transect locations with the occurrence of the plume delineated on each transect; (B) barge position and transects with the location of water samples

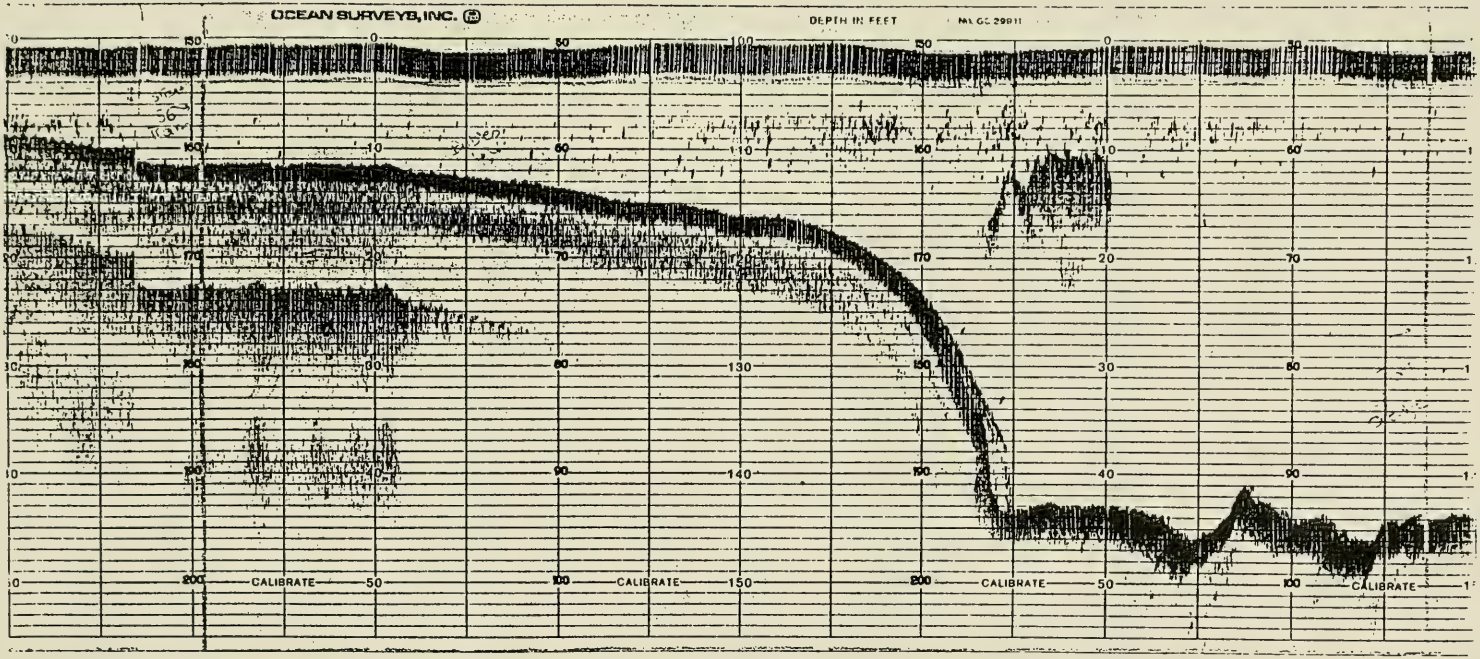


Figure 3-25. Traces of the plume observed 575 meters downcurrent, on the eastern side of the channel. Records are from traces obtained on November 18, Transect #56. Profile runs east to west.

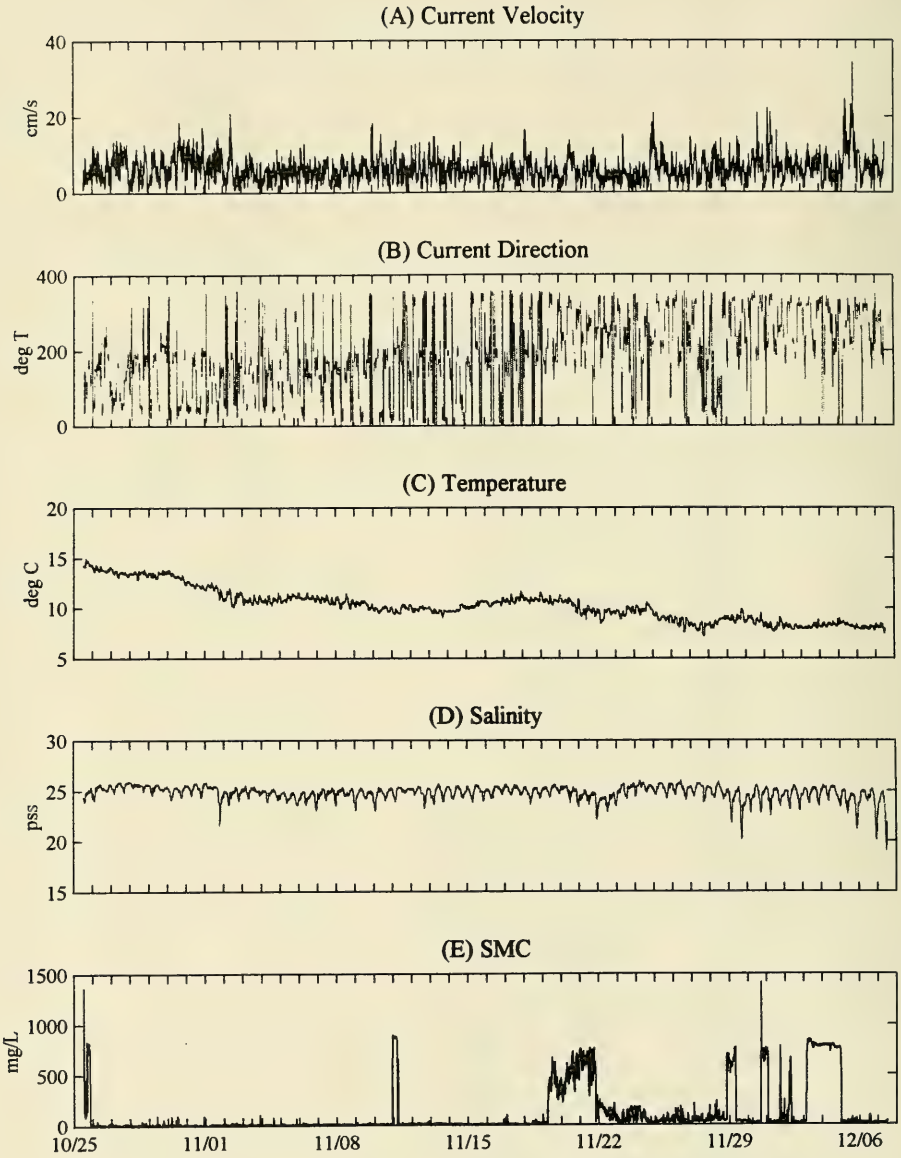


Figure 3-26. Time series plots for the complete DAISY deployment period, October 25 to December 7, 1993

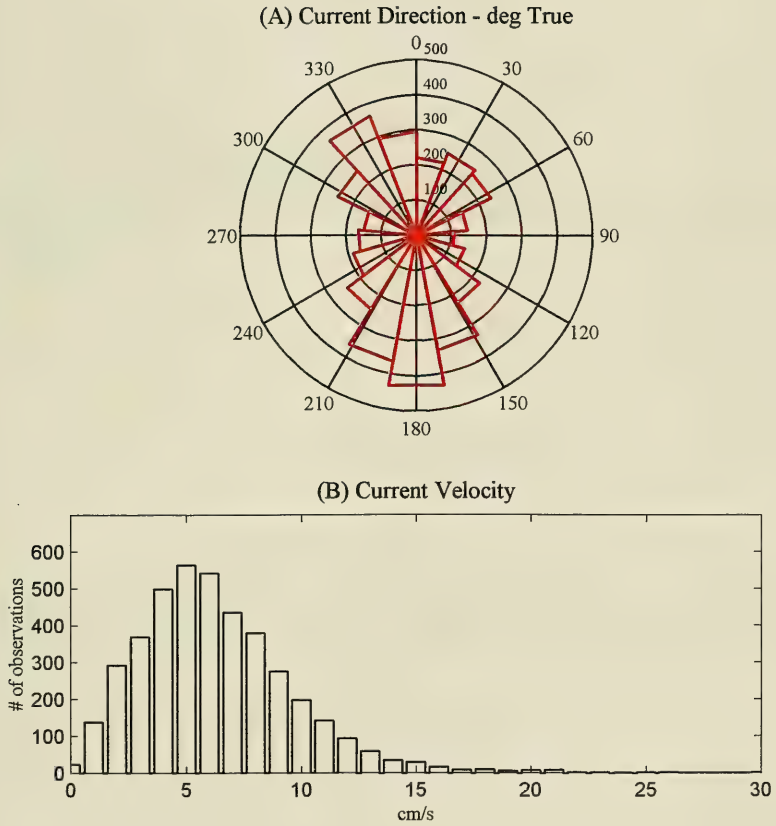


Figure 3-27. Summary plots for the DAISY current meter data: (A) rose histogram for current direction, and (B) current velocity histogram

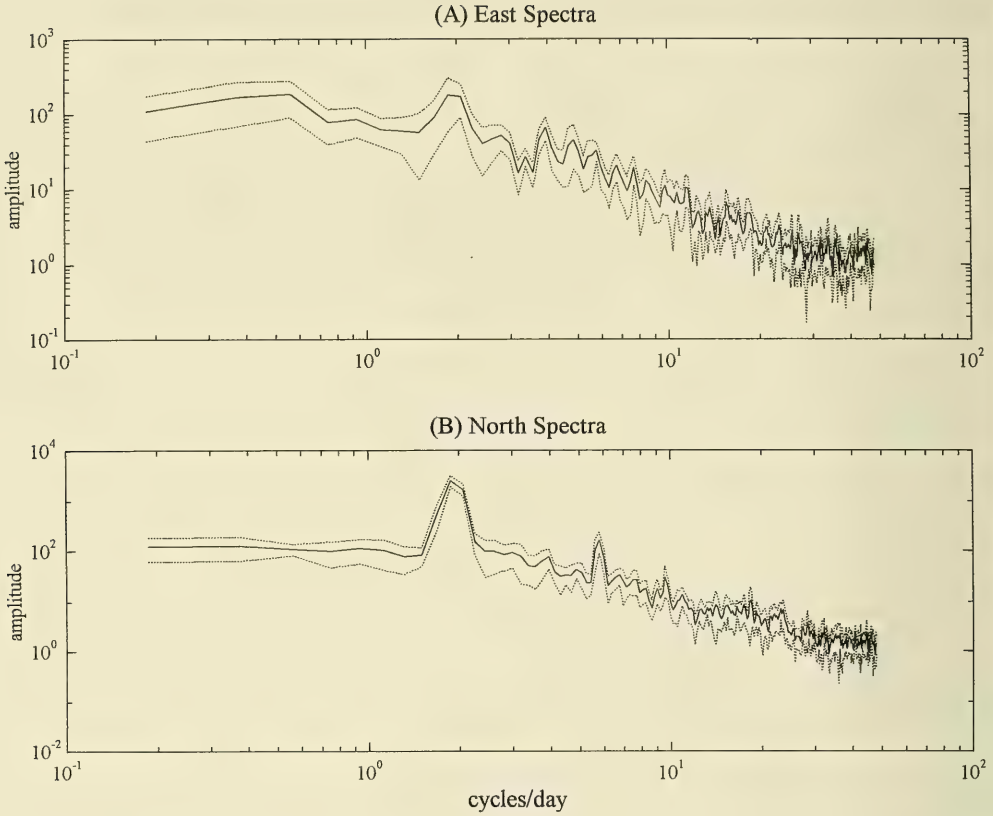


Figure 3-28. Energy spectra for the velocity components (A) east, or u component, and (B) north, or v component. Dotted lines represent the 95% confidence limits for the spectral estimation.

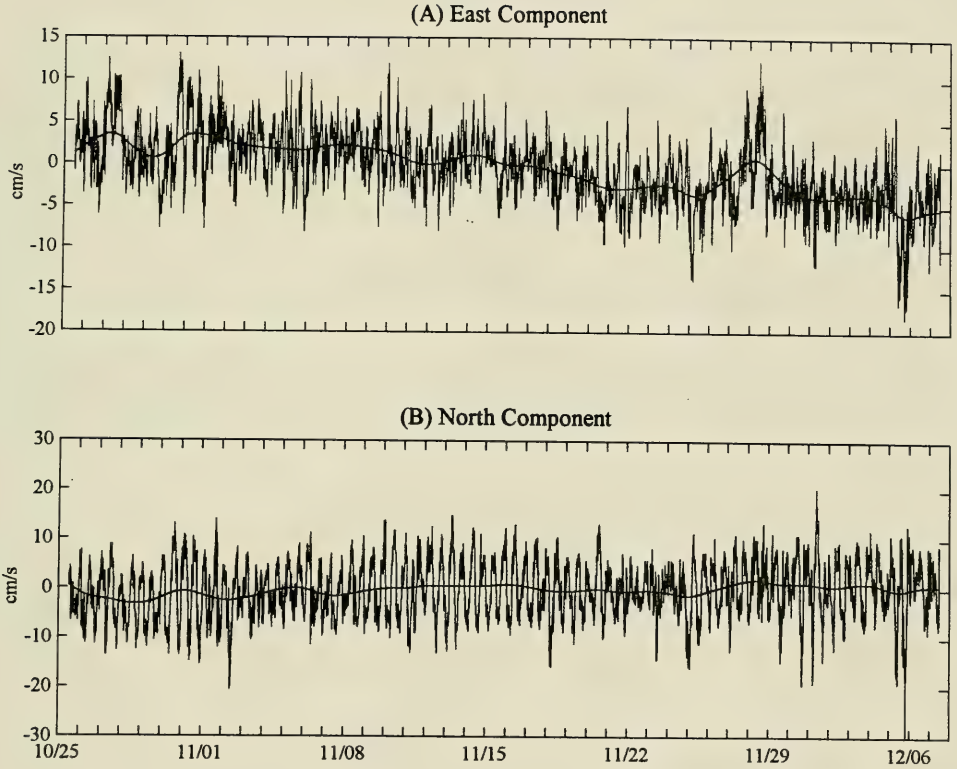


Figure 3-29. The low-pass filtered data, represented by the solid black line, plotted over the original time series for each velocity component: (A) east, or u component, and (B) the north, or v component

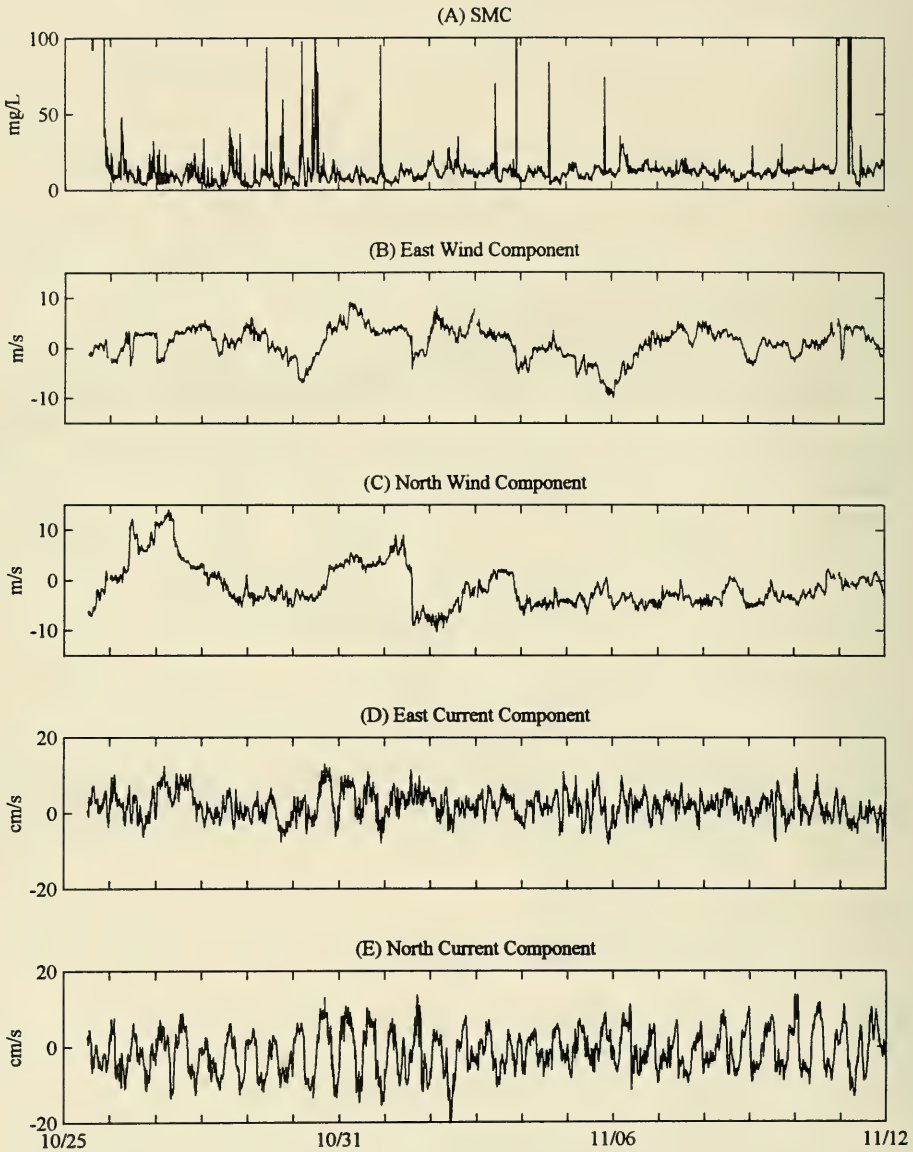


Figure 3-30. The suspended material concentration data compared with wind and current data for the first half of the deployment, October 25 to November 11, 1993

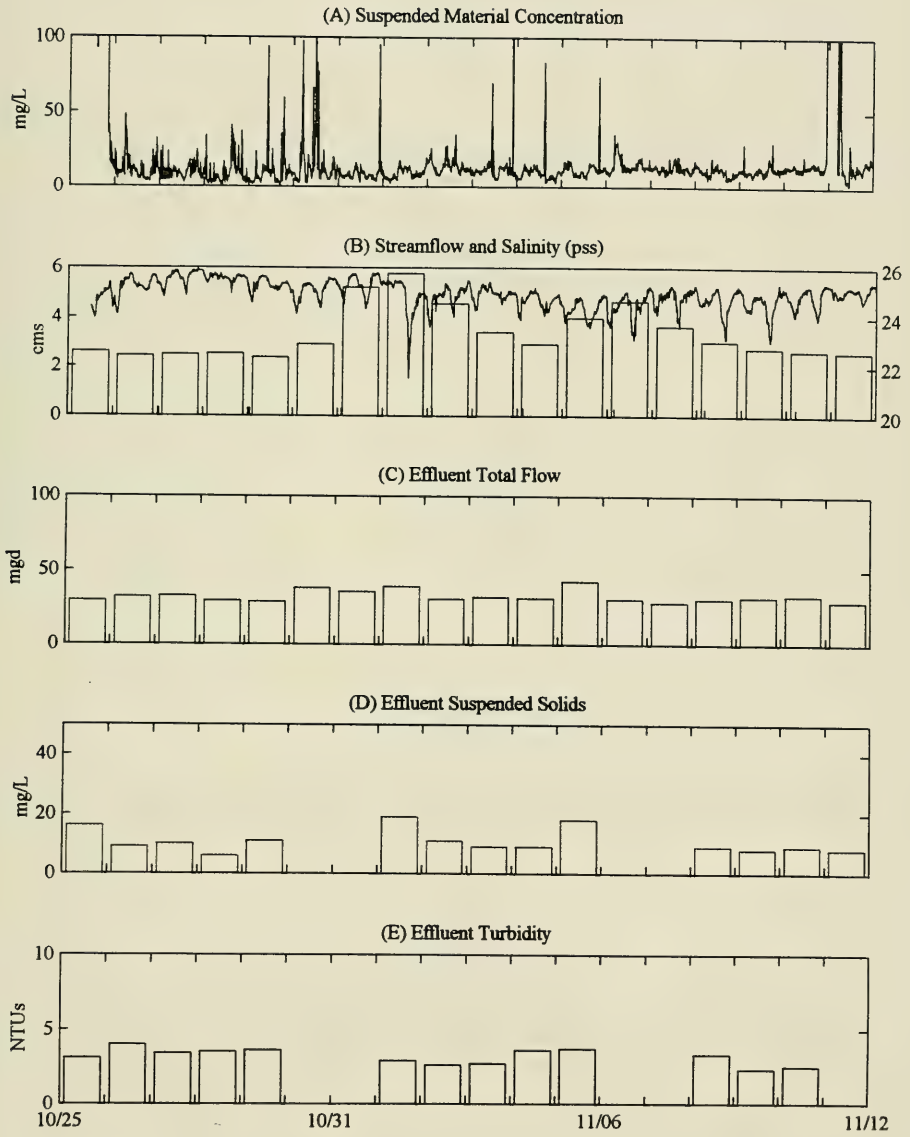


Figure 3-31. The suspended material concentration data compared with stream flow and effluent from the East Haven Pollution Abatement Facility for the first half of the deployment, October 25 to November 11, 1993

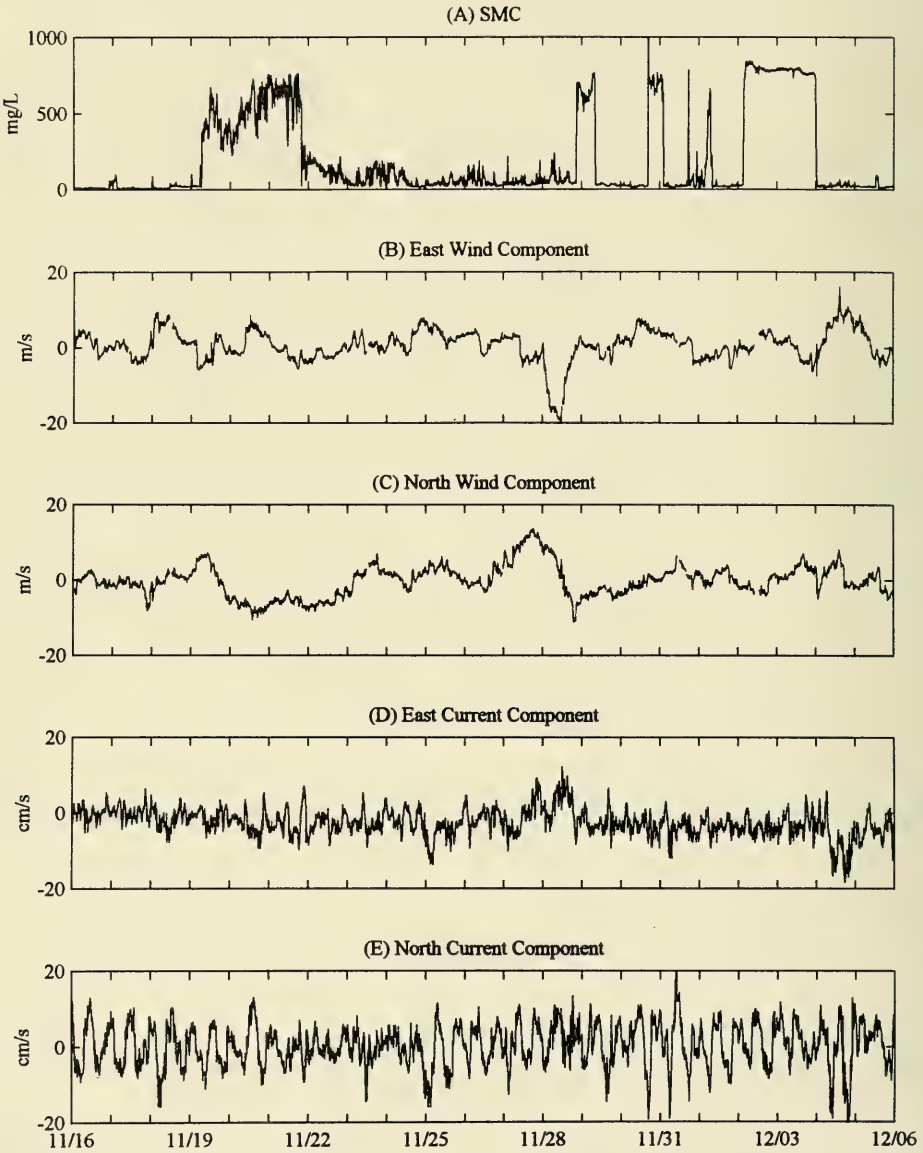


Figure 3-32. Enlargement of the period during which the largest SMC perturbations were observed, November 16 to December 6, 1993. Concentration data are compared with wind and current data.

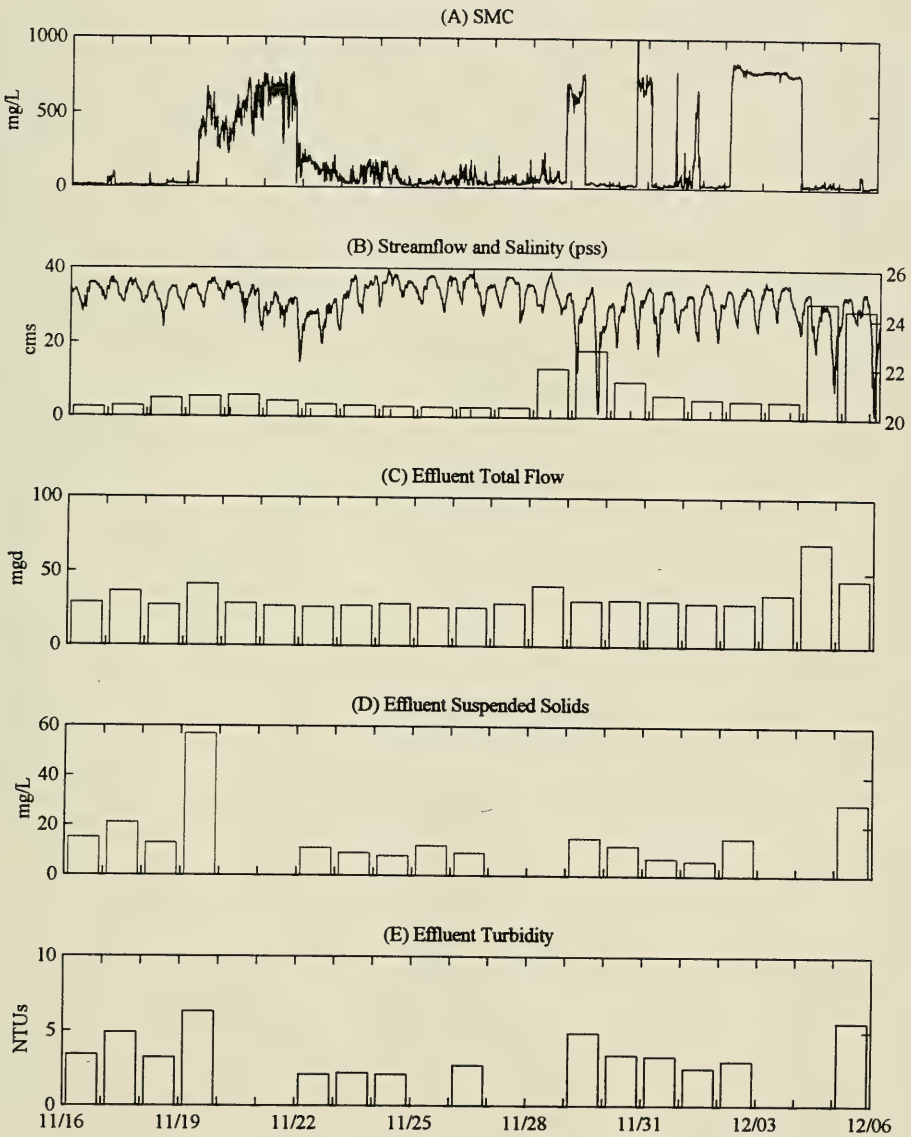
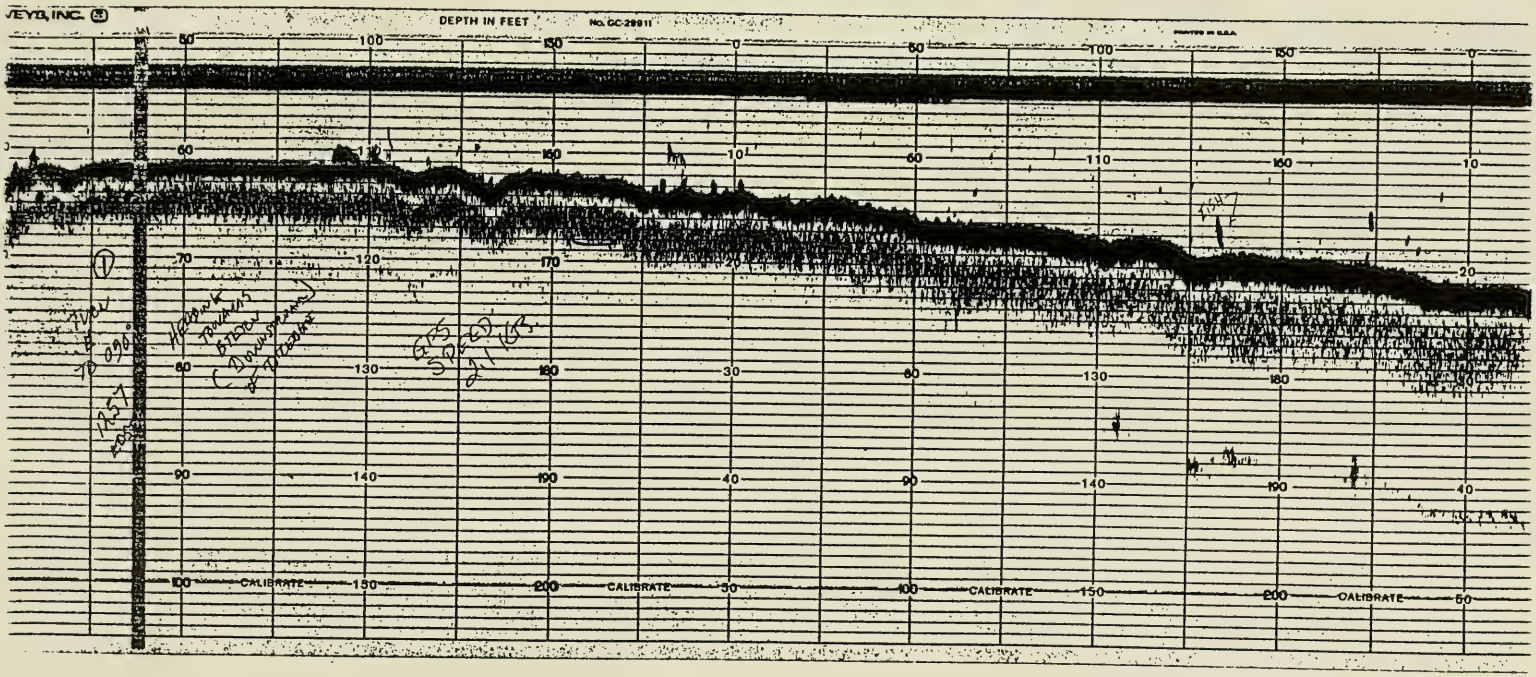


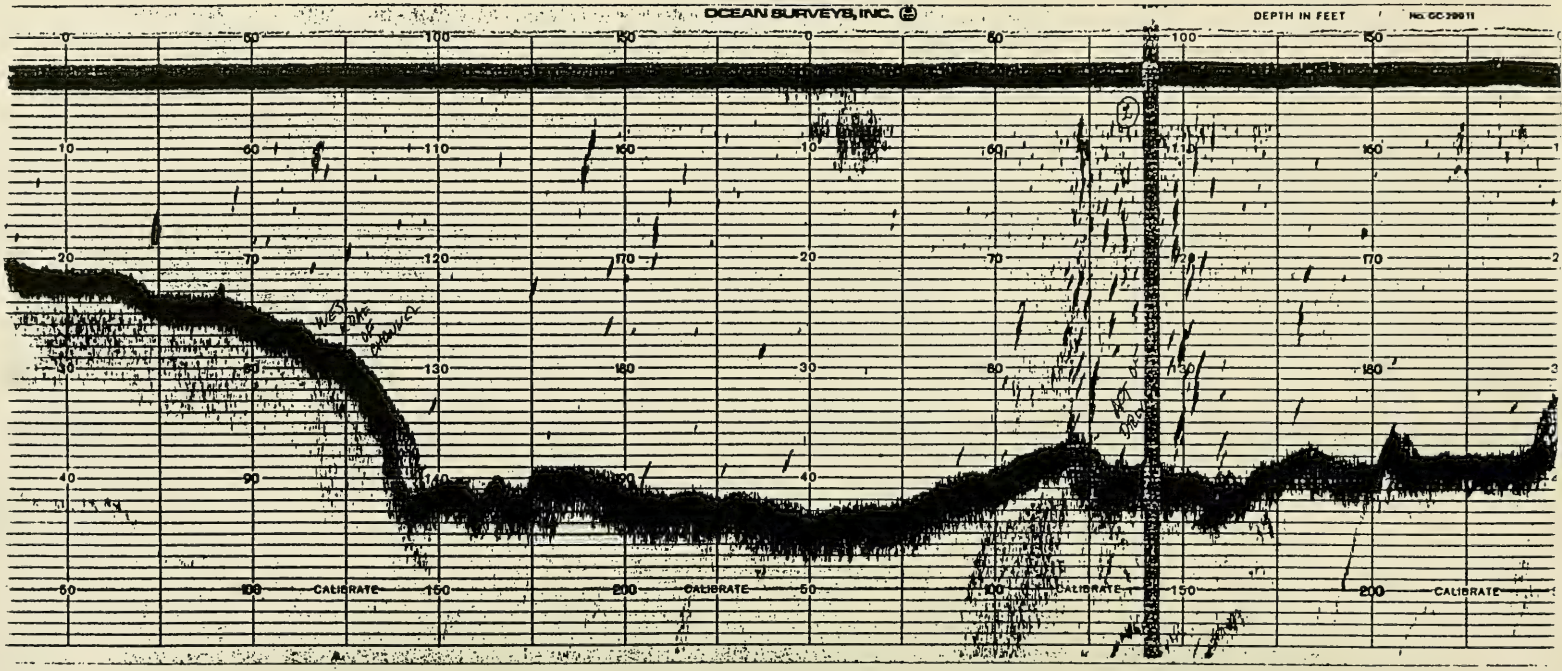
Figure 3-33. The suspended material concentration data compared with stream flow and effluent data obtained from the East Haven Pollution Abatement Facility for the period November 16 to December 6, 1993

APPENDIX I

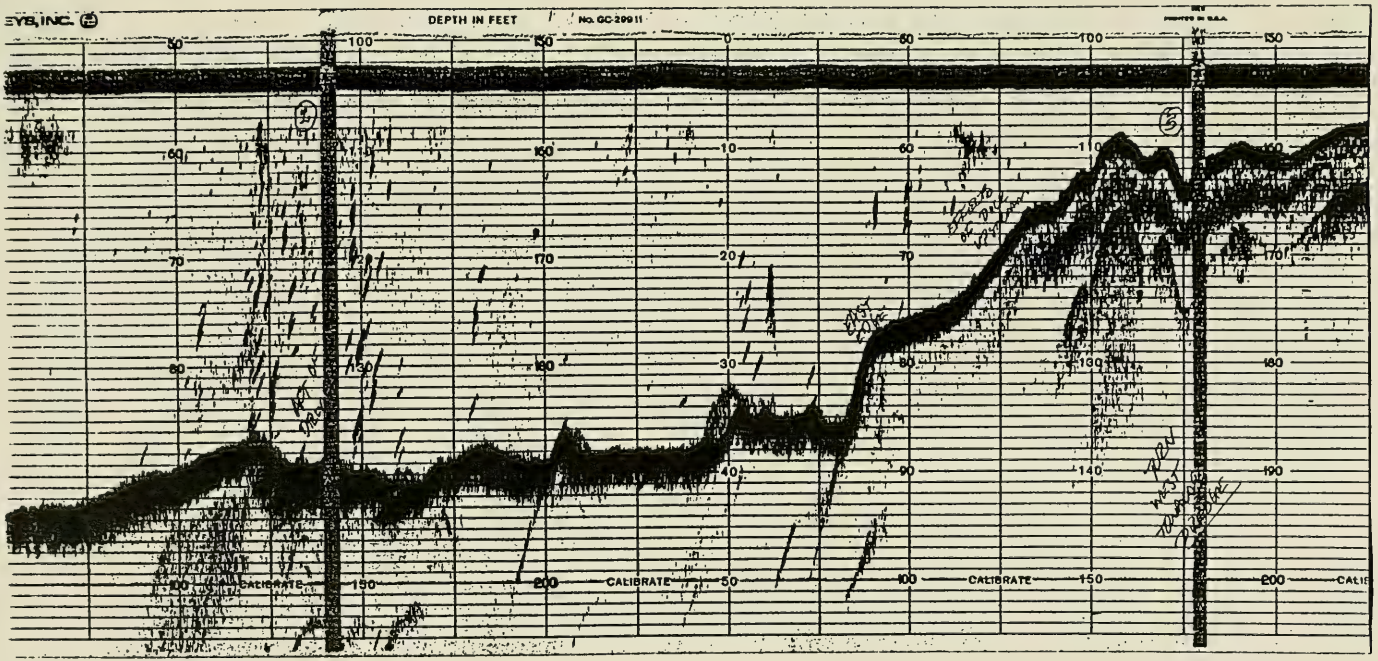
ECHO SOUNDER TRACES



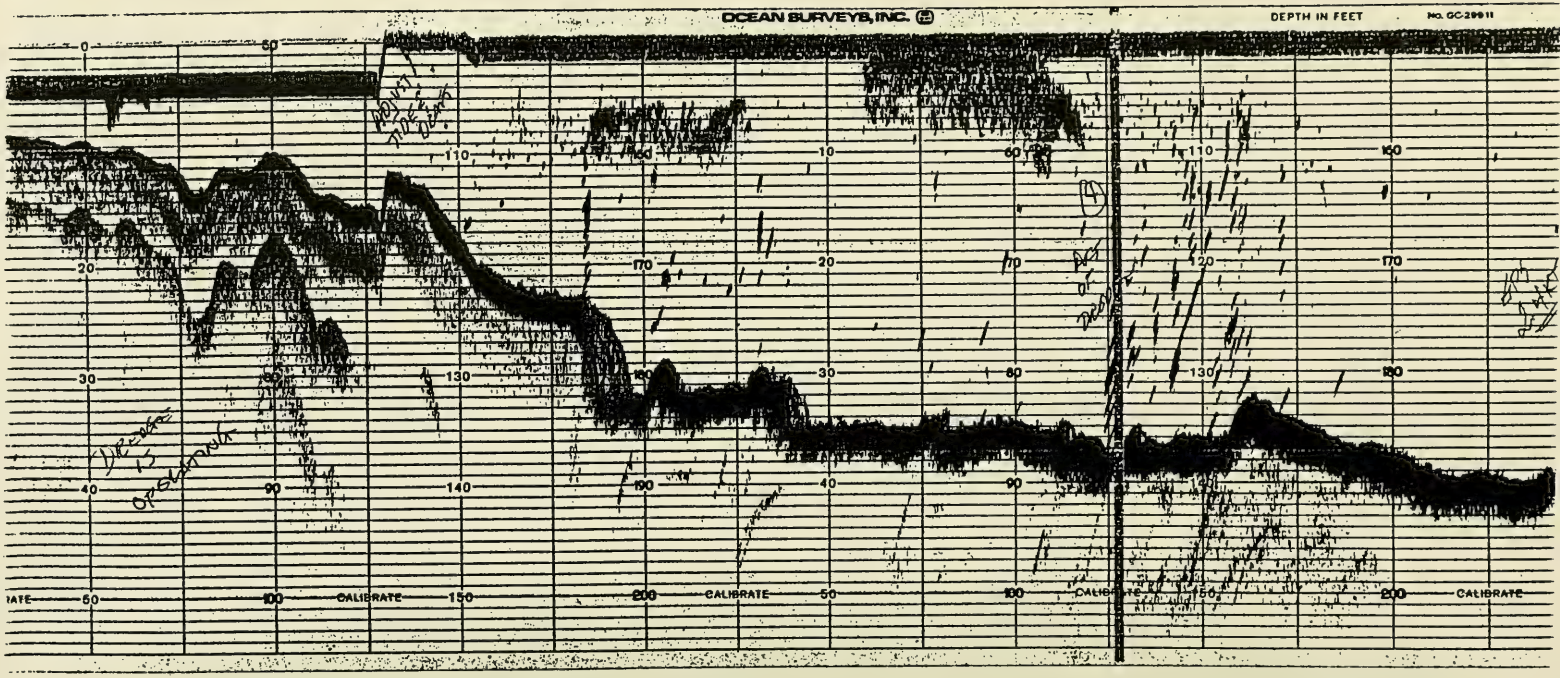
Beginning segment of Transect A acoustic profile surveyed on 25 October 1993; profile runs west to east



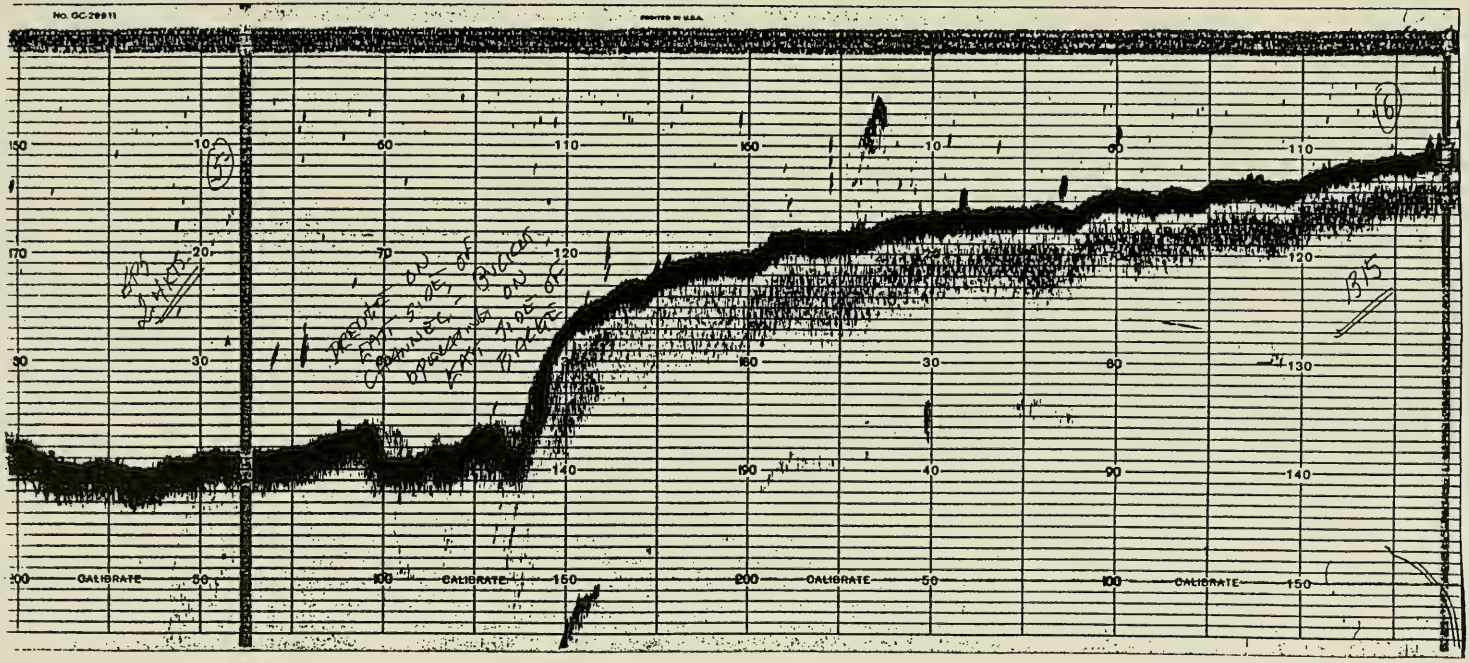
Middle segment of Transect A acoustic profile surveyed on 25 October 1993; profile runs west to east



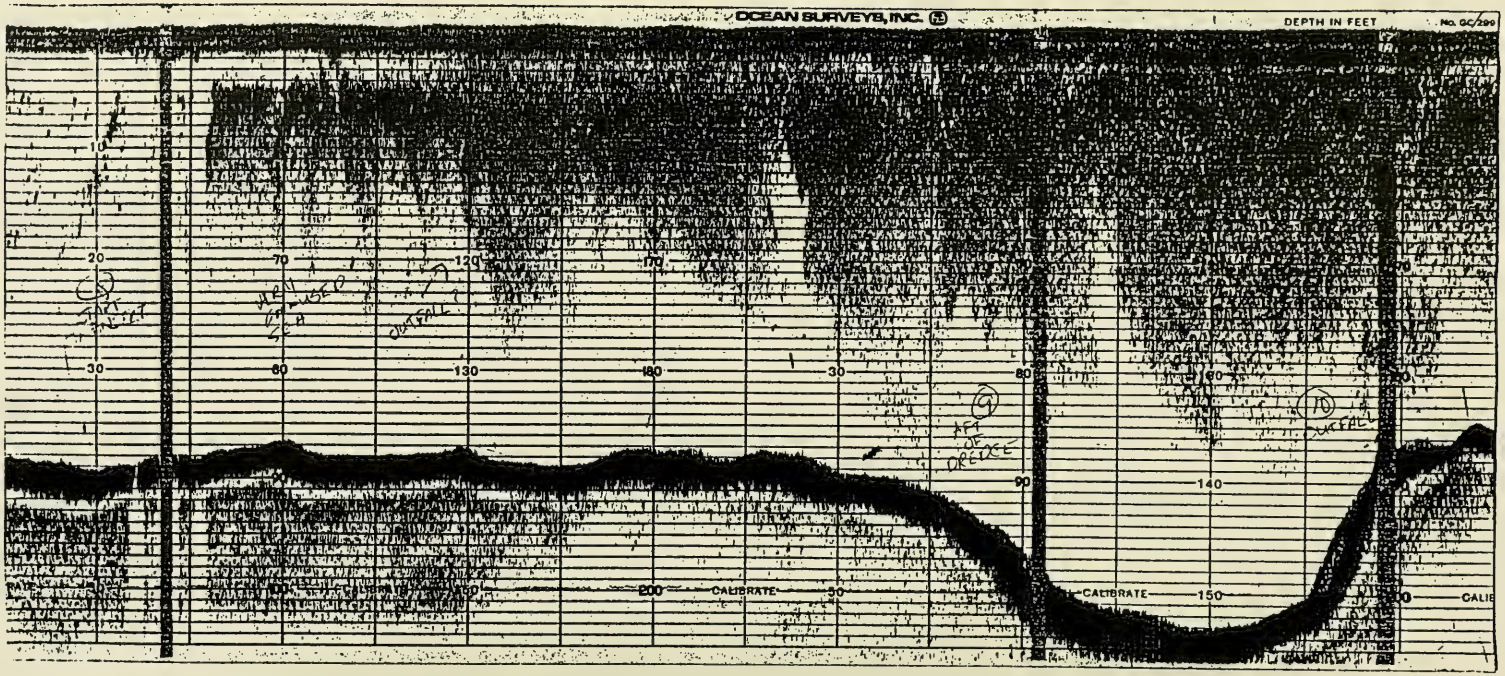
End segment of Transect A acoustic profile surveyed on 25 October 1993; profile runs west to east



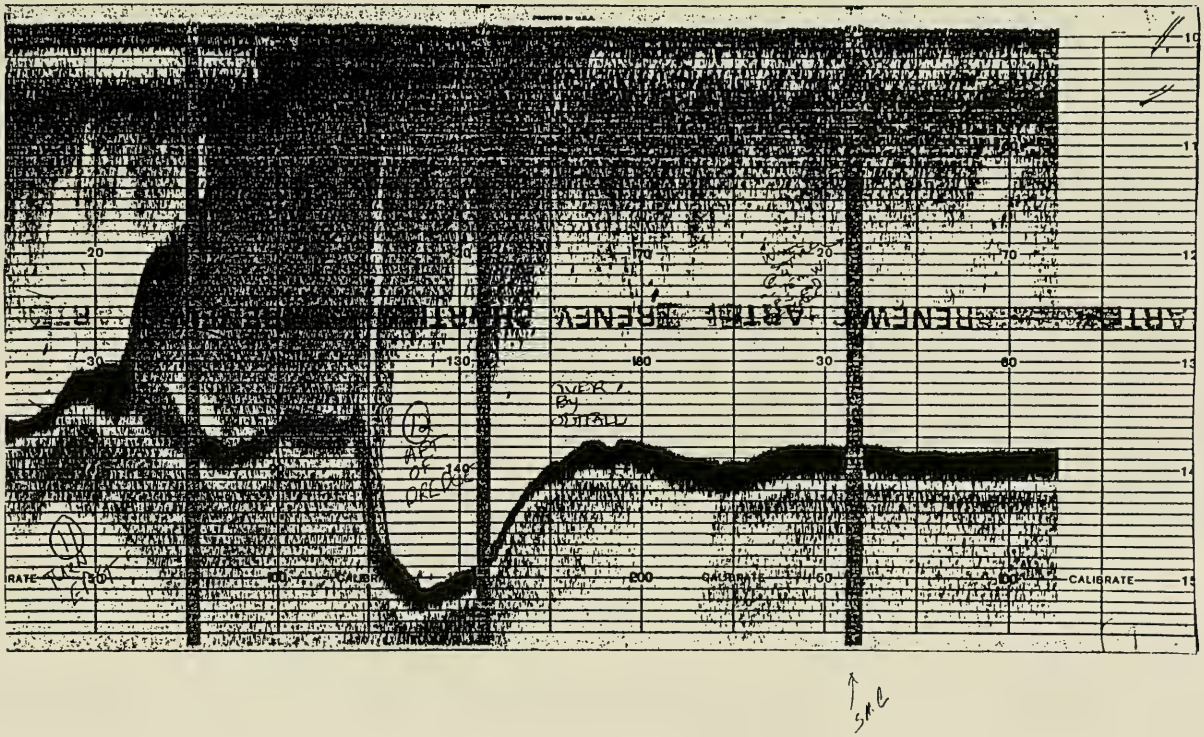
Beginning segment of Transect B acoustic profile surveyed on 25 October 1993; profile runs east to west



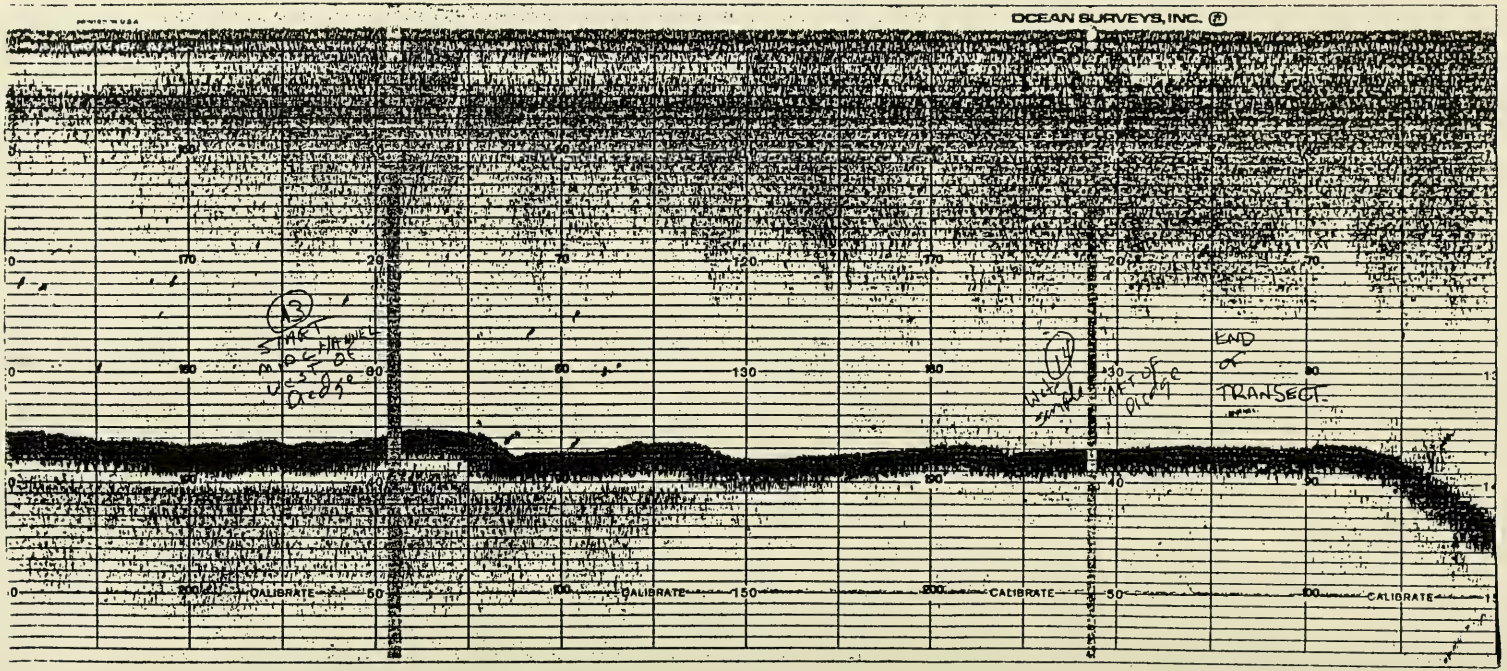
End segment of Transect B acoustic profile surveyed on 25 October 1993; profile runs east to west



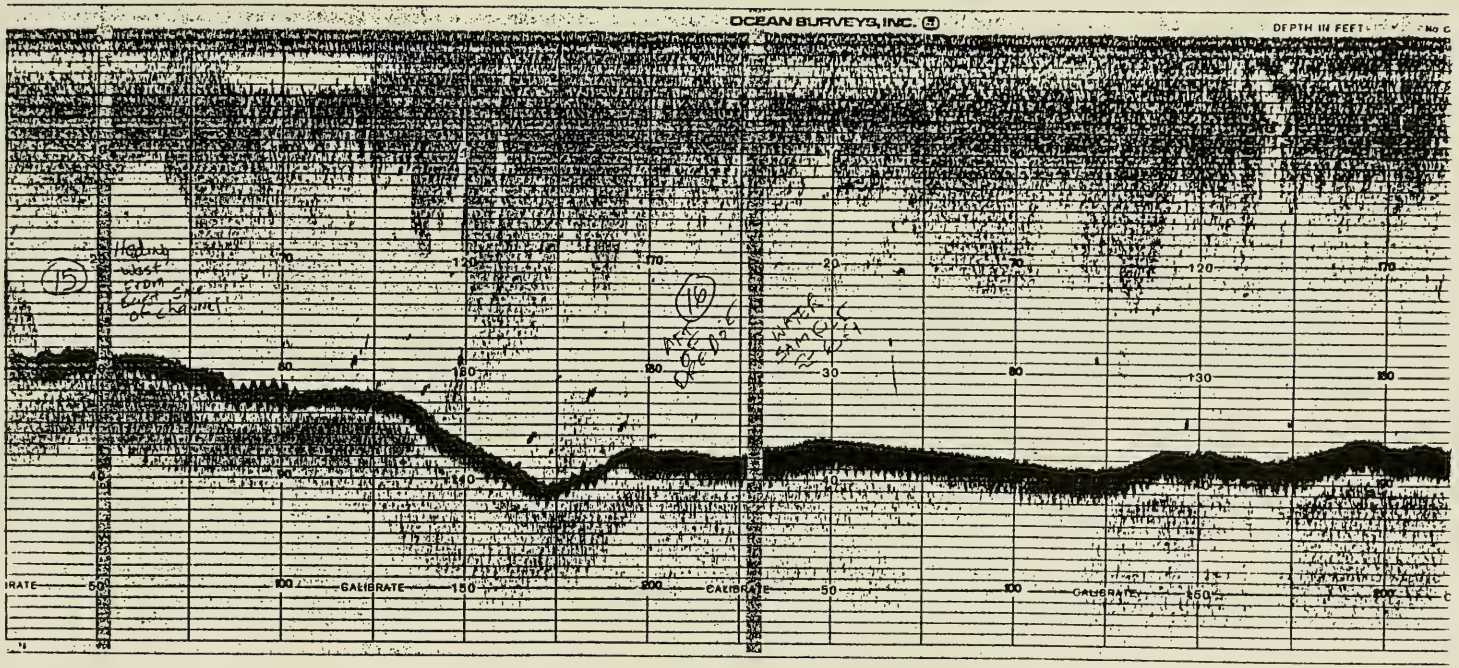
Transect D acoustic profile surveyed on 25 October 1993; profile runs west to east



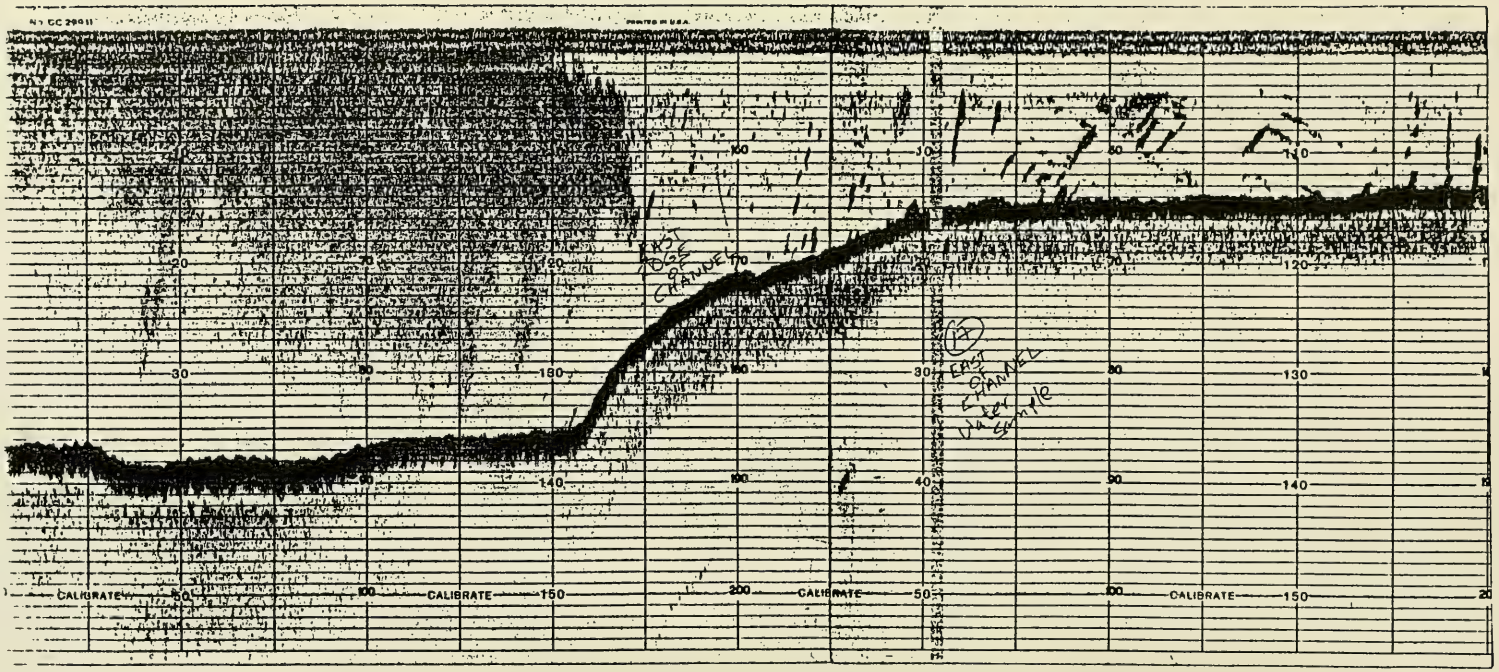
Transect E acoustic profile surveyed on 25 October 1993; profile runs east to west



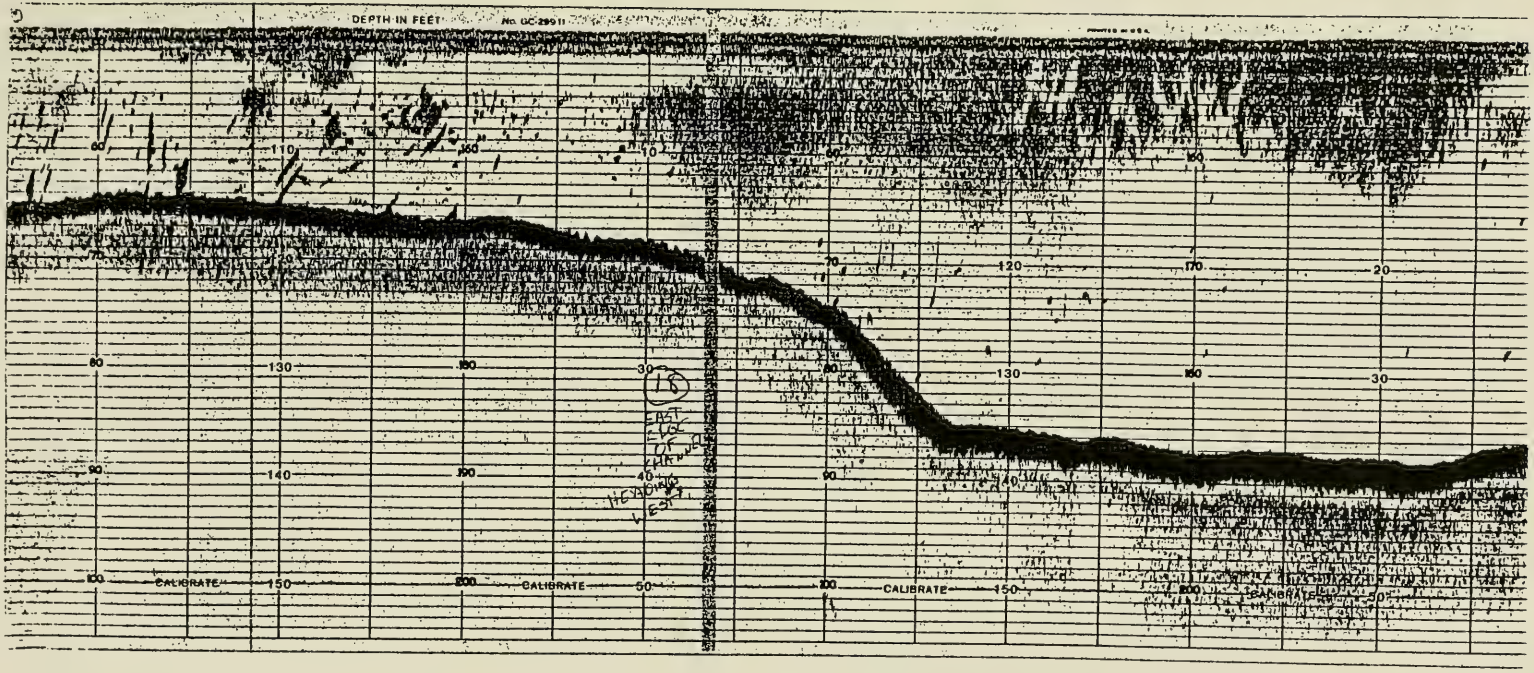
Transect F accoustic profile surveyed on 25 October 1993; profile runs west to east



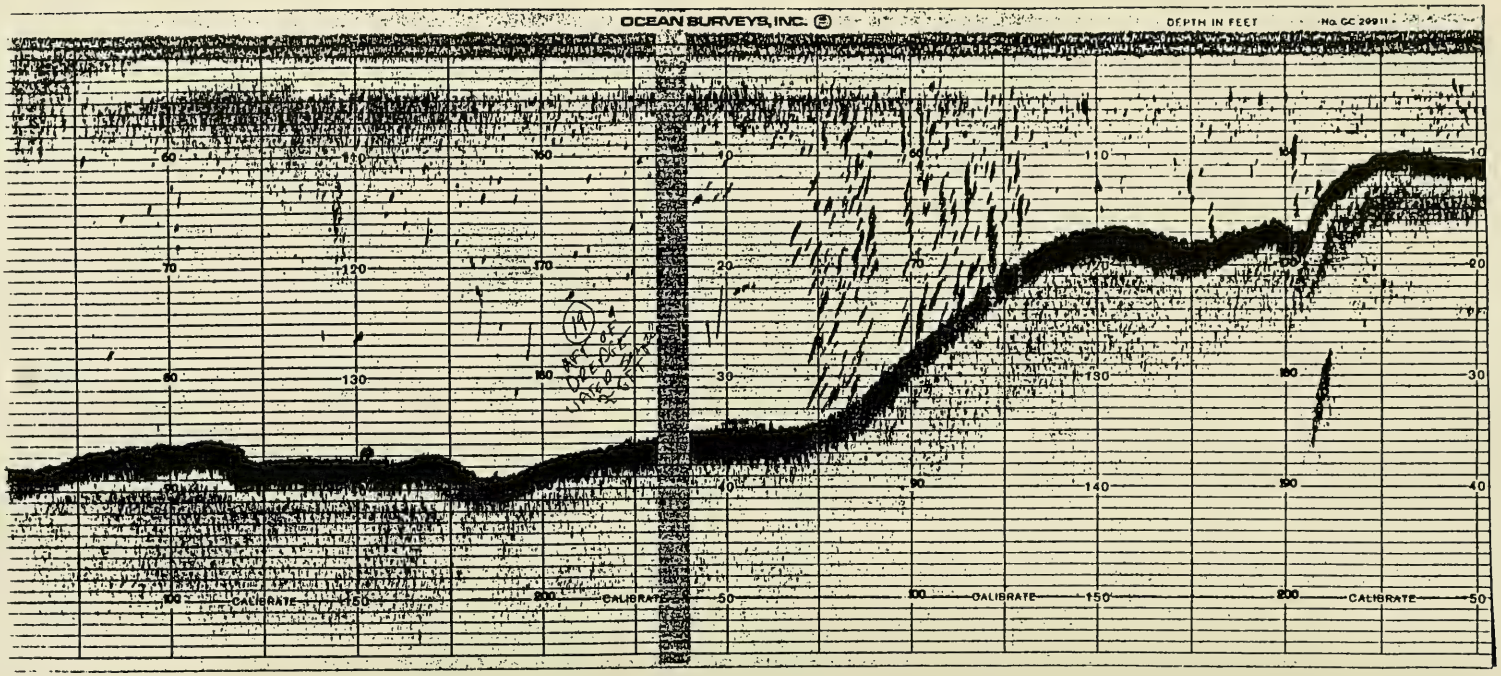
Beginning segment of Transect G acoustic profile surveyed on 25 October 1993; profile runs east to west



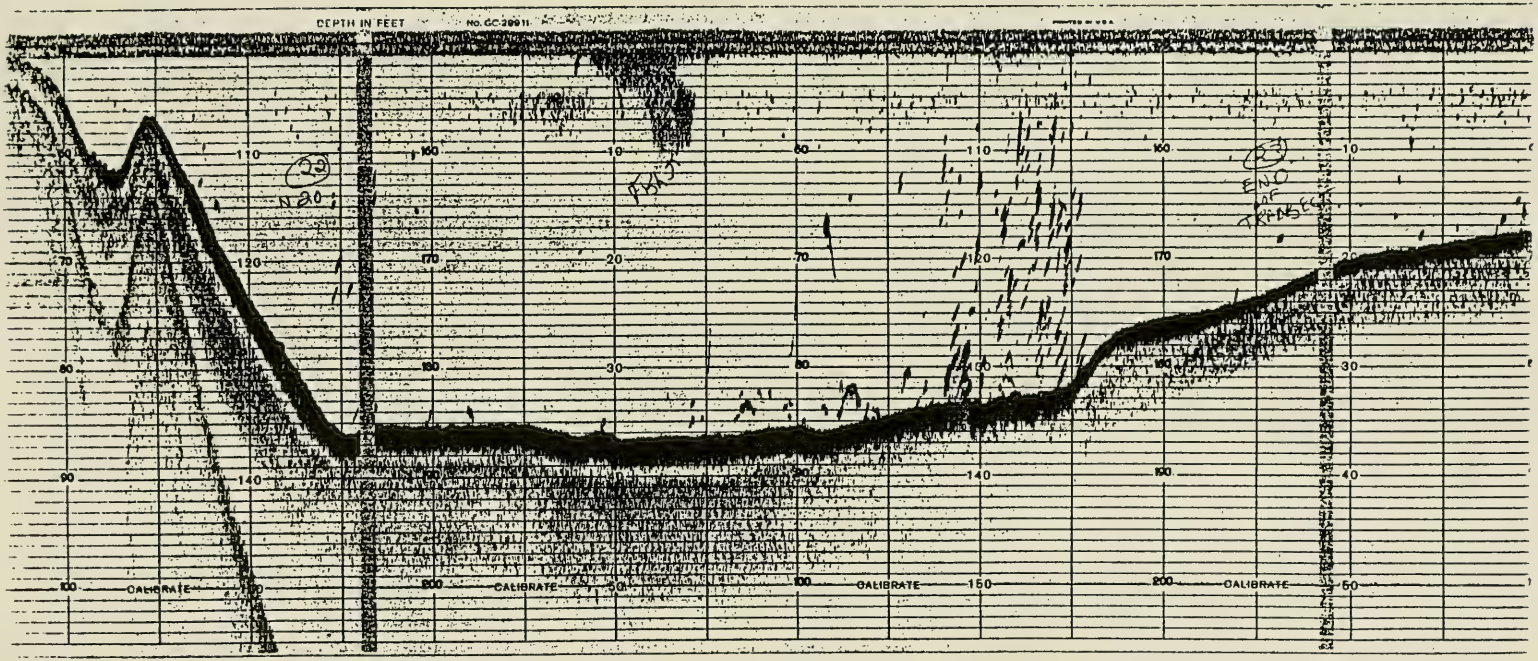
End segment of Transect G acoustic profile surveyed on 25 October 1993; profile runs east to west



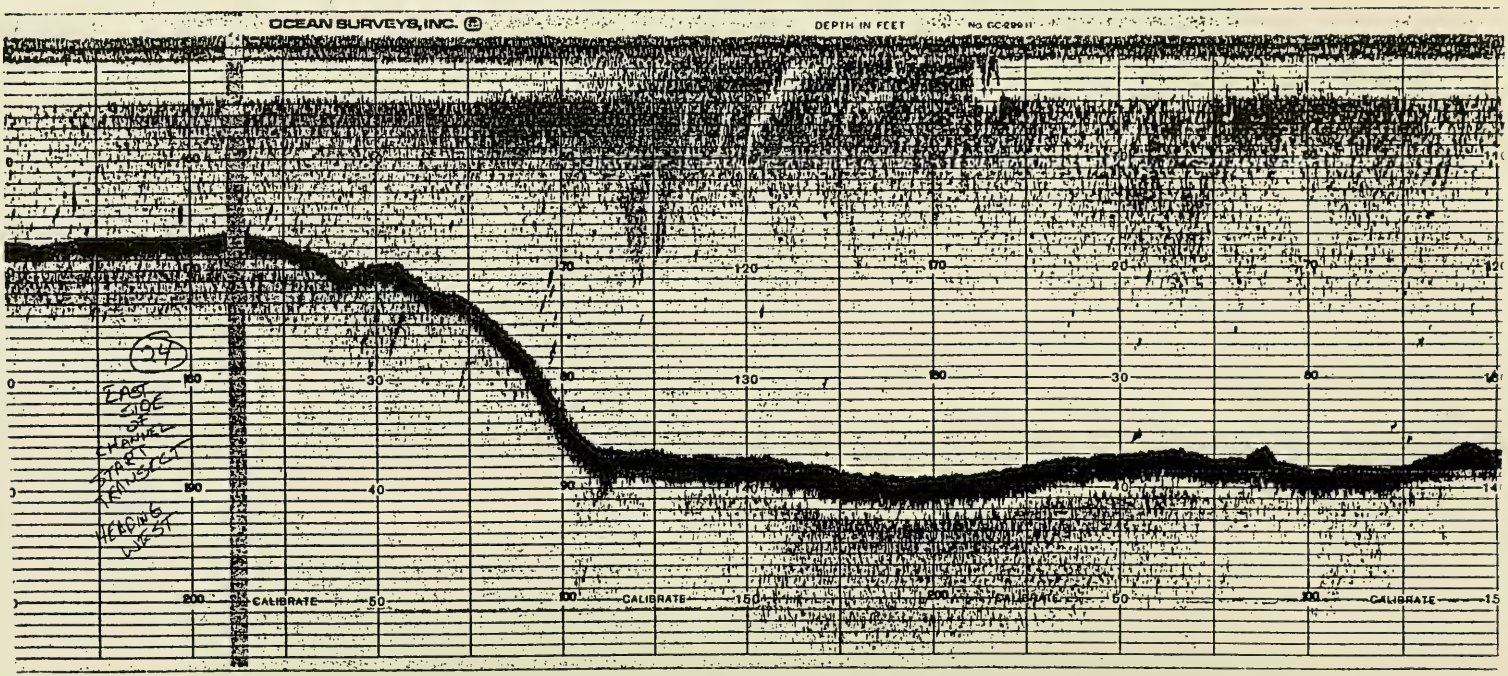
Beginning segment of Transect H acoustic profile surveyed on 25 October 1993; profile runs west to east



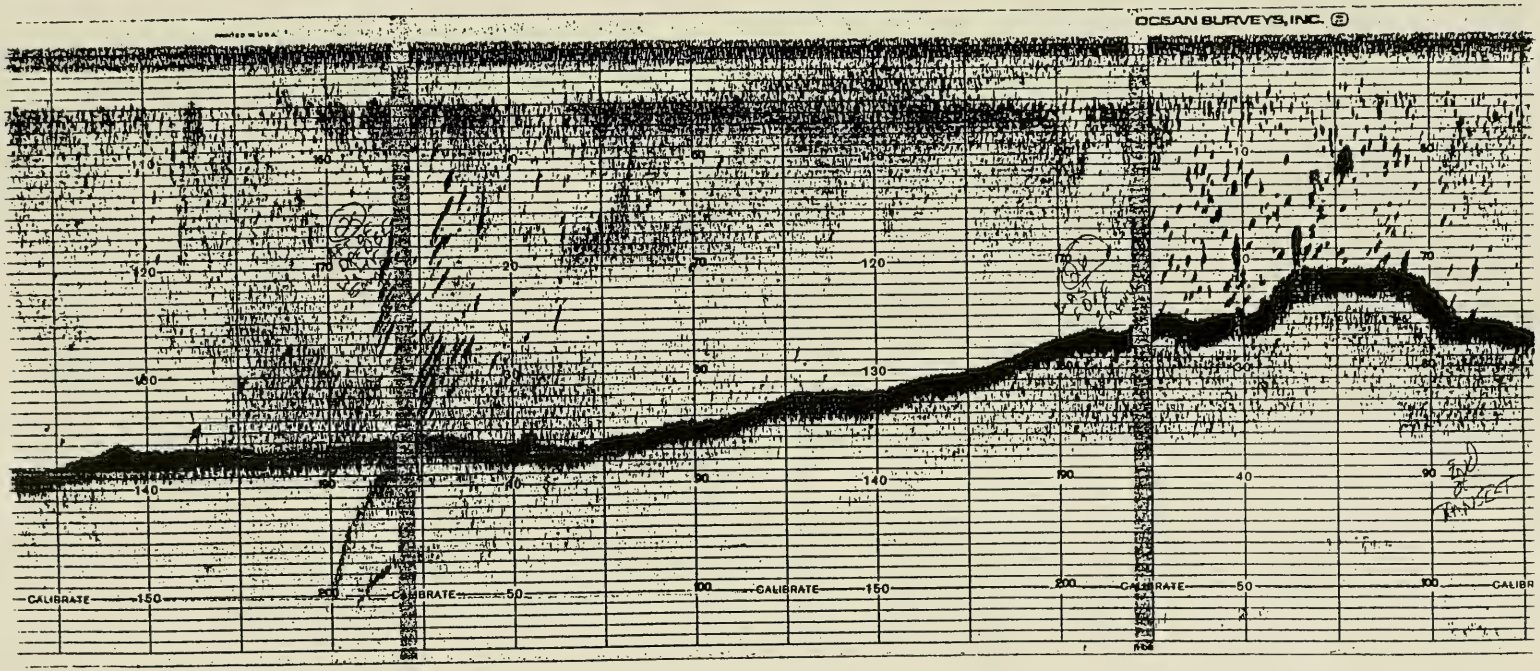
End segment of Transect H acoustic profile surveyed on 25 October 1993; profile runs west to east



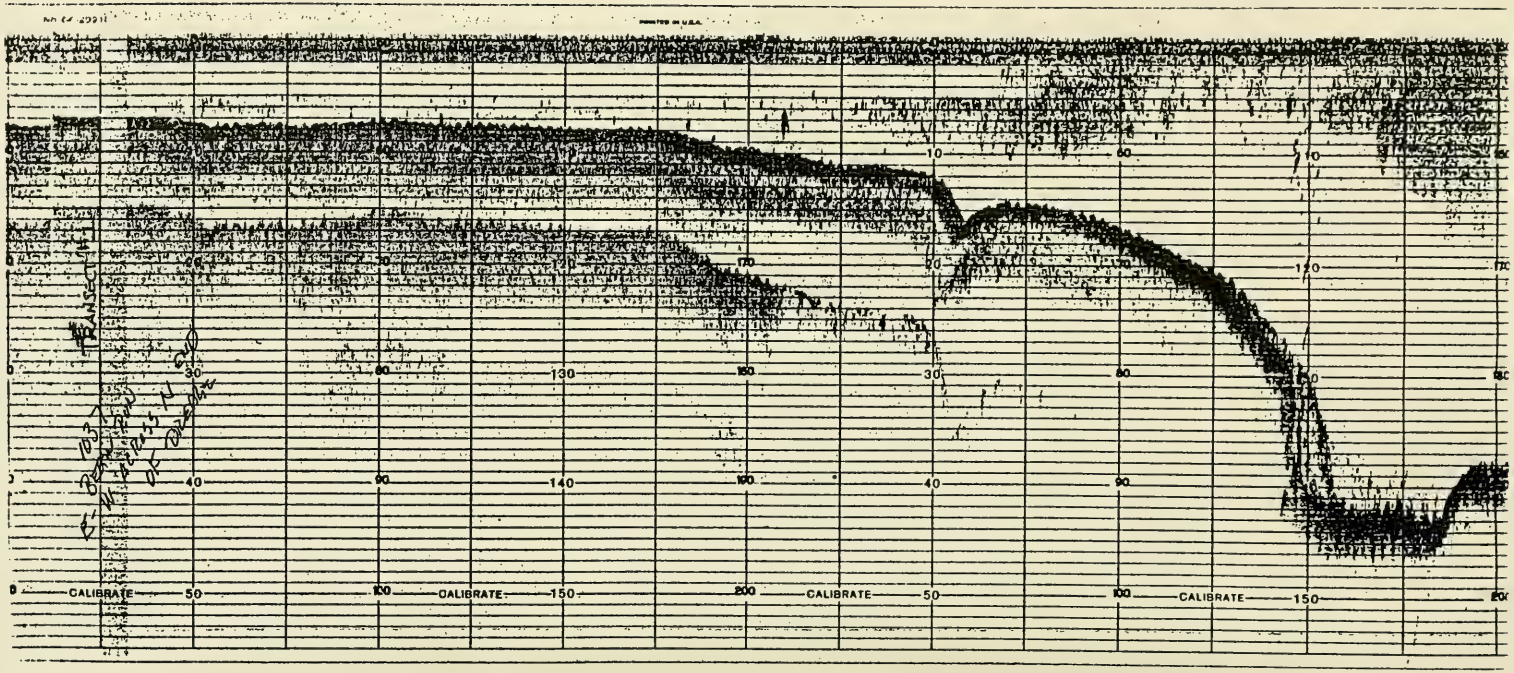
Transect I acoustic profile surveyed on 25 October 1993; profile runs east to west



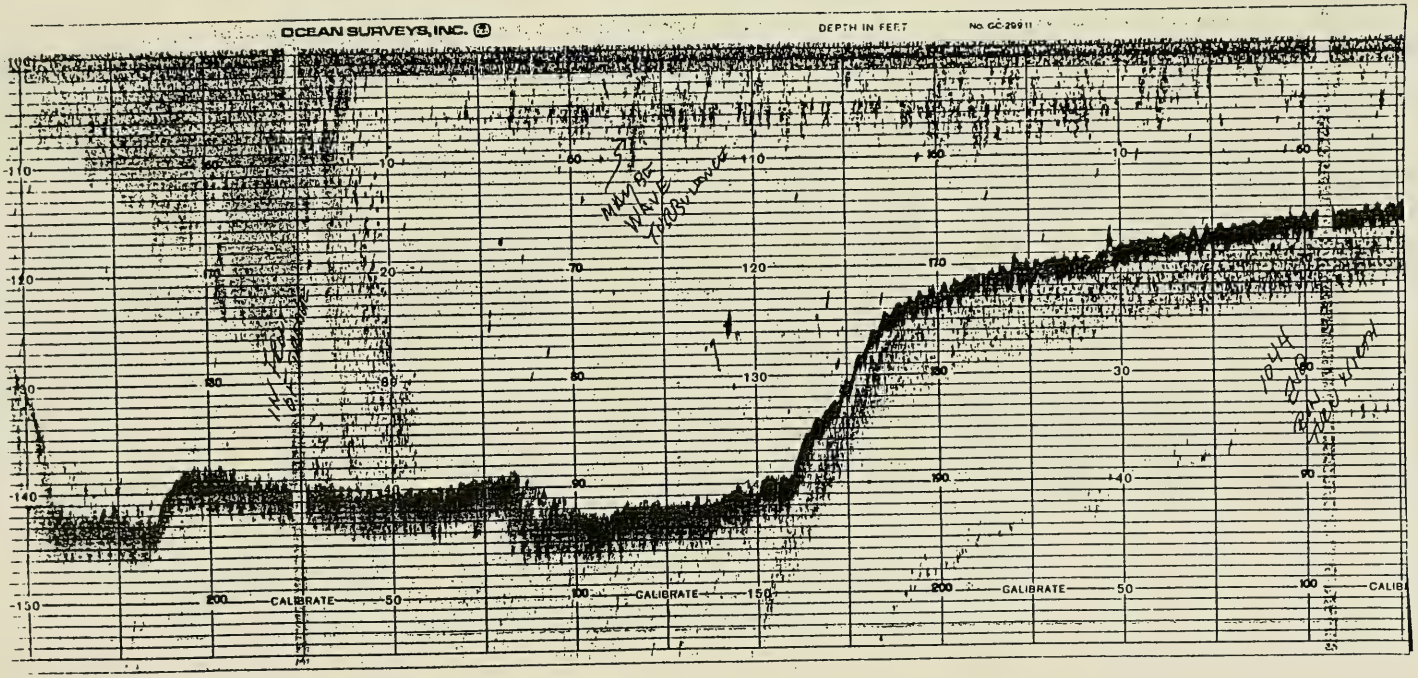
Beginning segment of Transect J acoustic profile surveyed on 25 October 1993; profile runs west to east



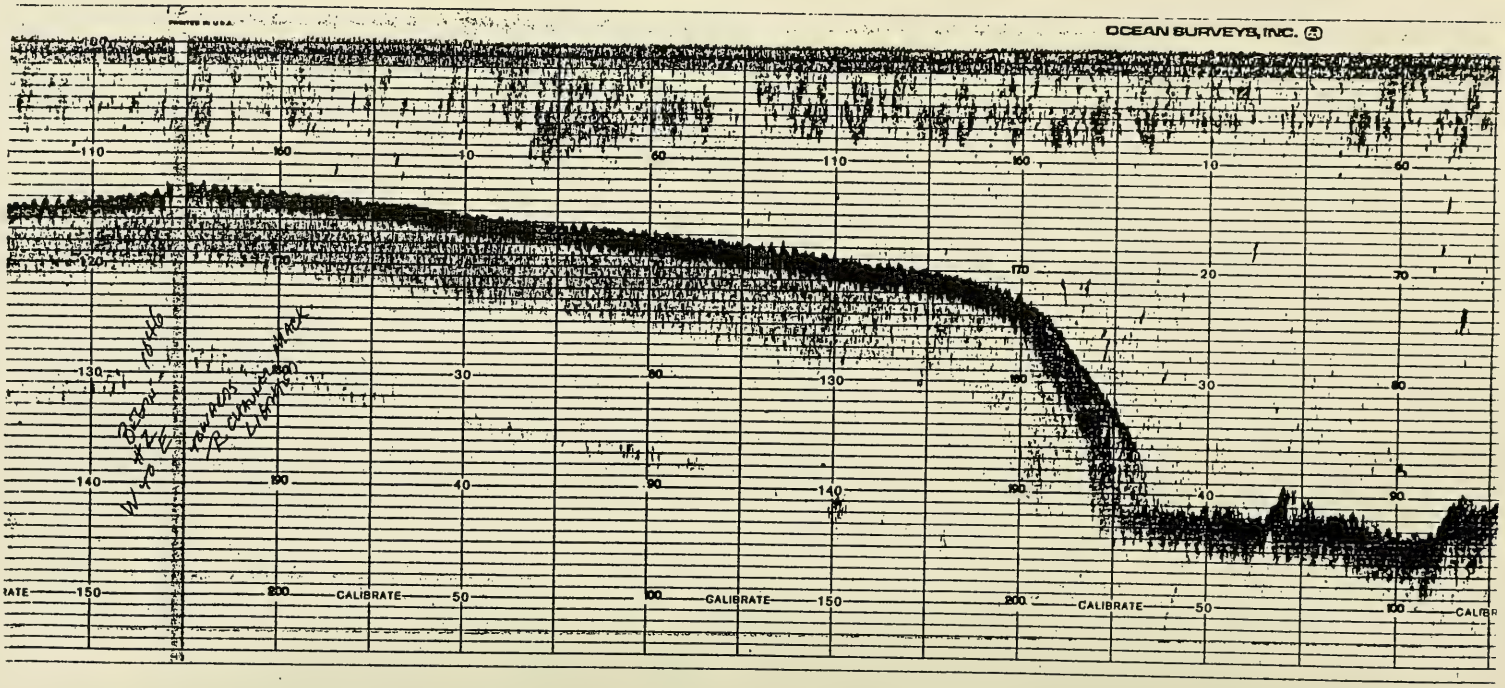
End segment of Transect J acoustic profile surveyed on 25 October 1993; profile runs west to east



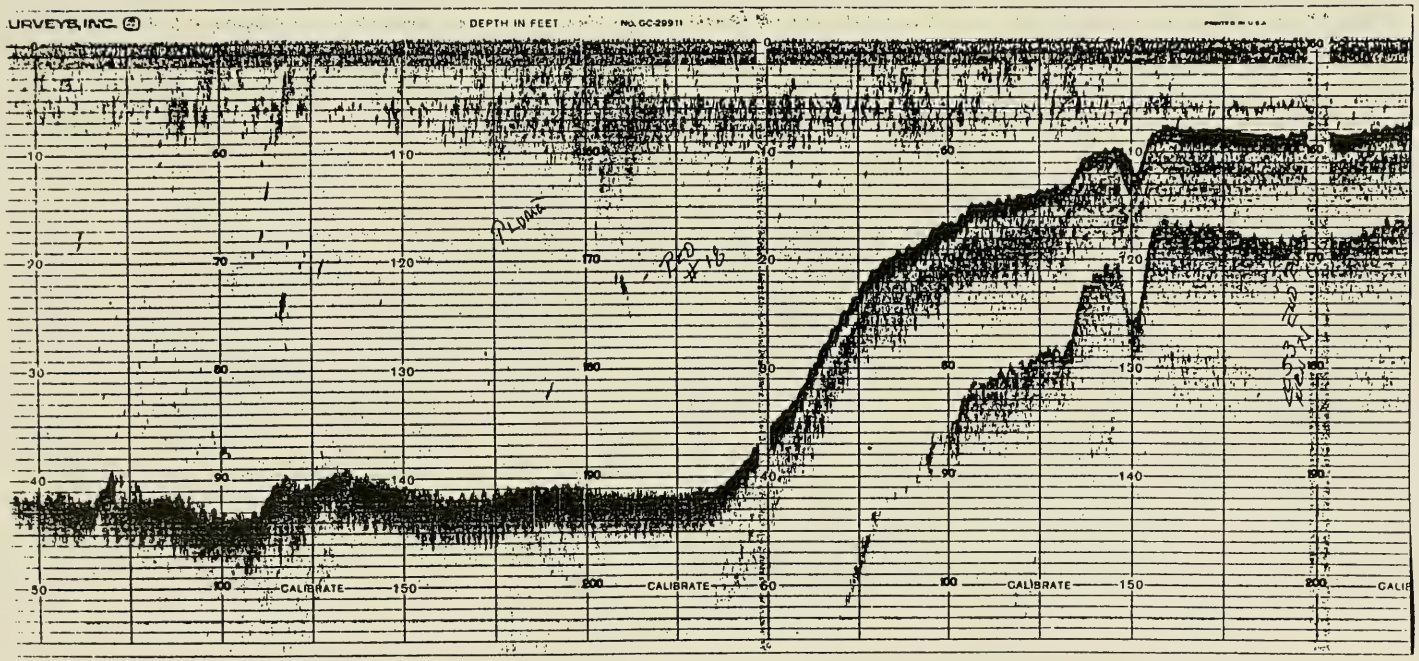
Beginning segment of Transect #1 acoustic survey of 2 November 1993; profile runs east to west



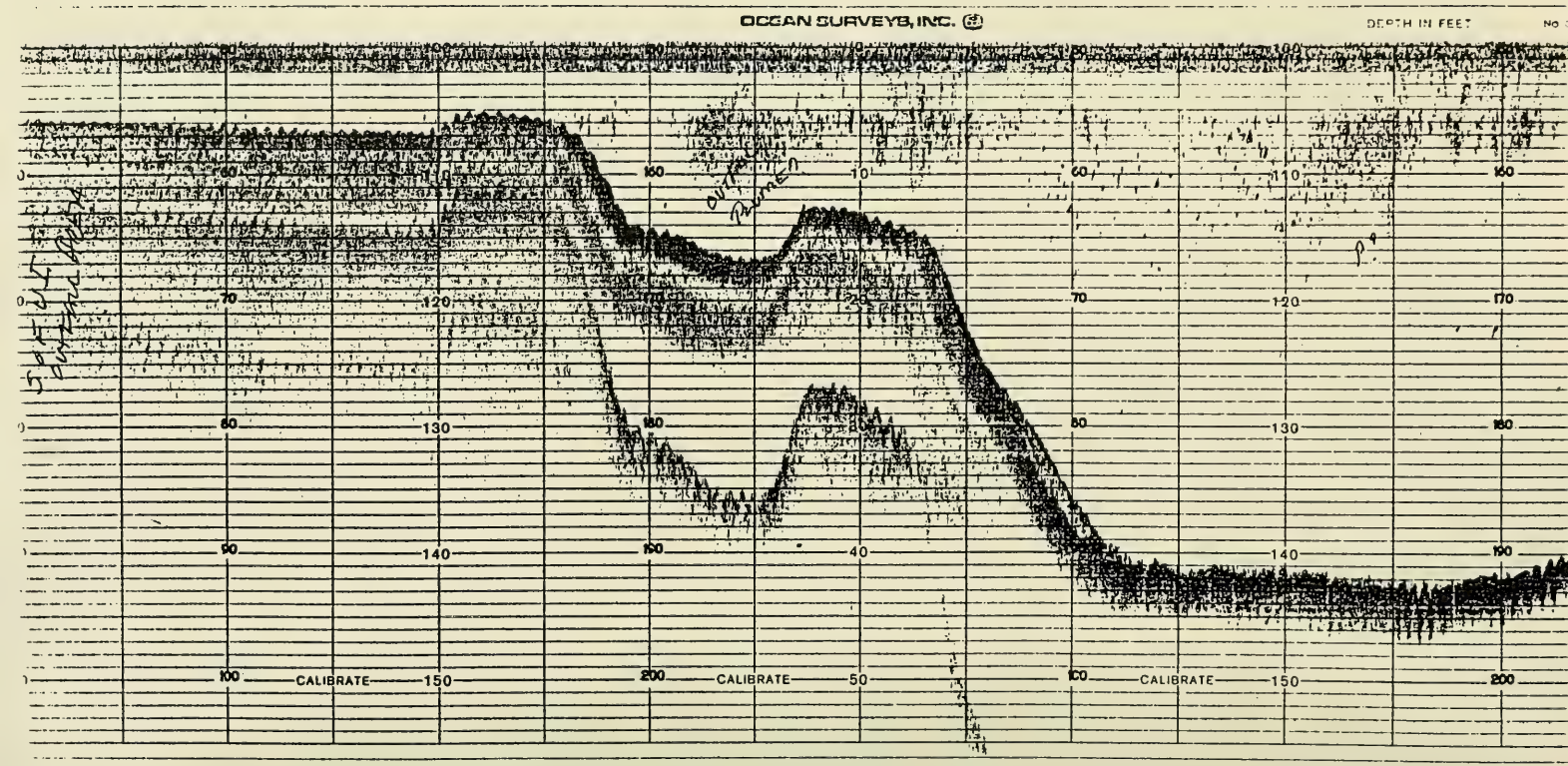
End segment of Transect #1 acoustic survey of 2 November 1993; profile runs east to west



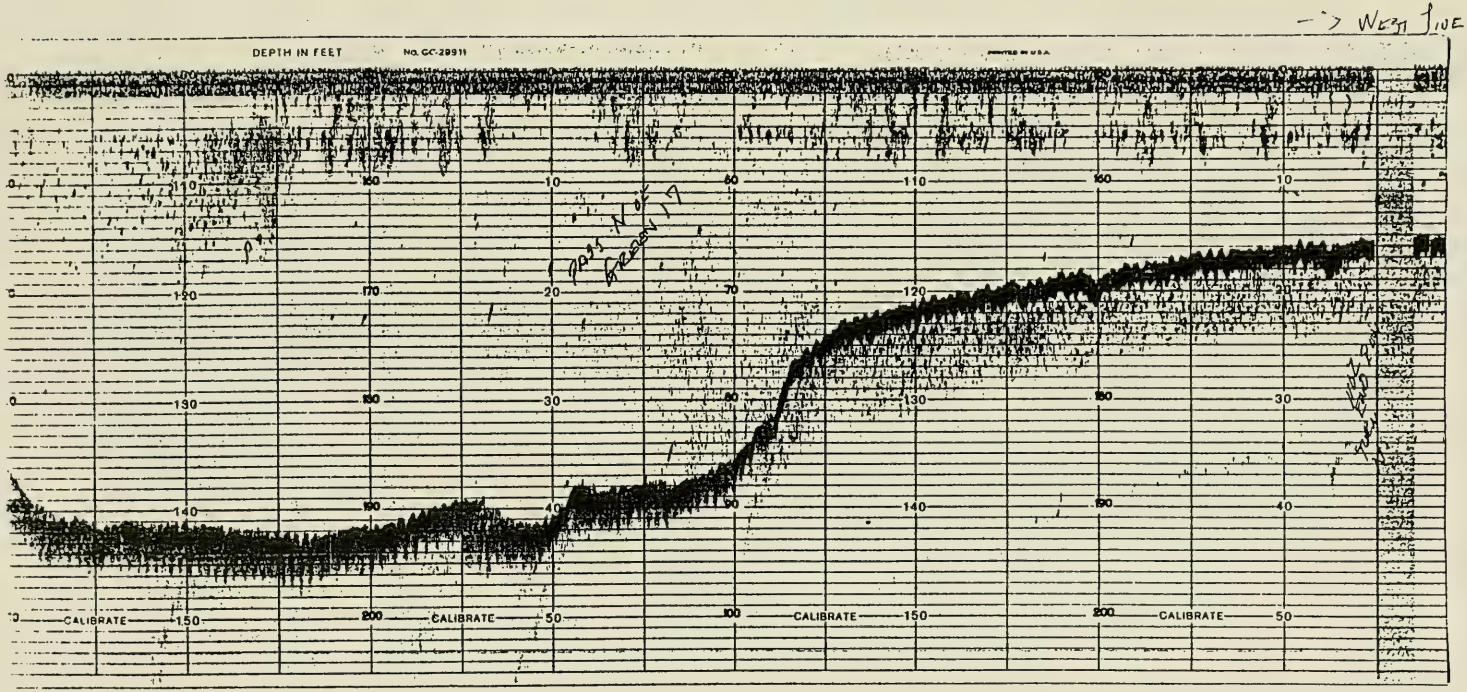
Beginning segment of Transect #2 acoustic survey of 2 November 1993; profile runs west to east



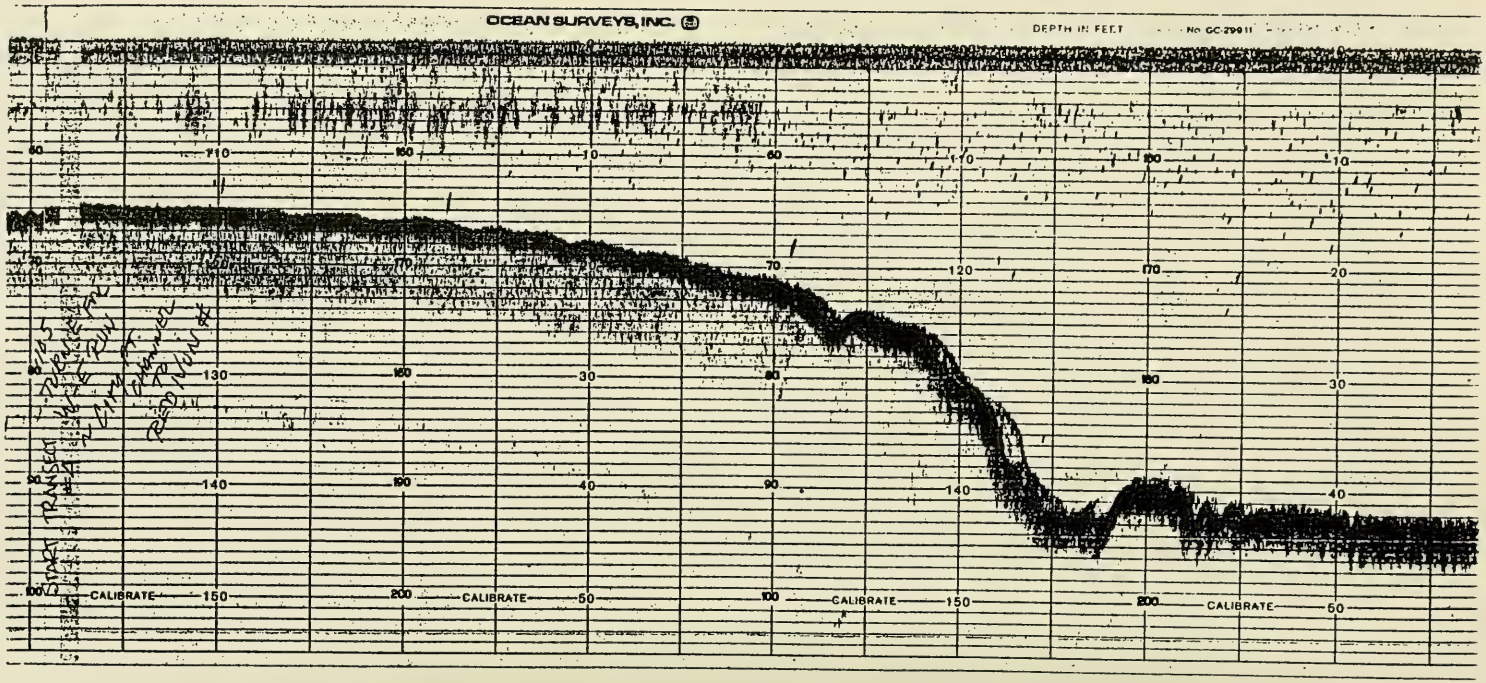
End segment of Transect #2 acoustic survey of 2 November 1993; profile runs west to east



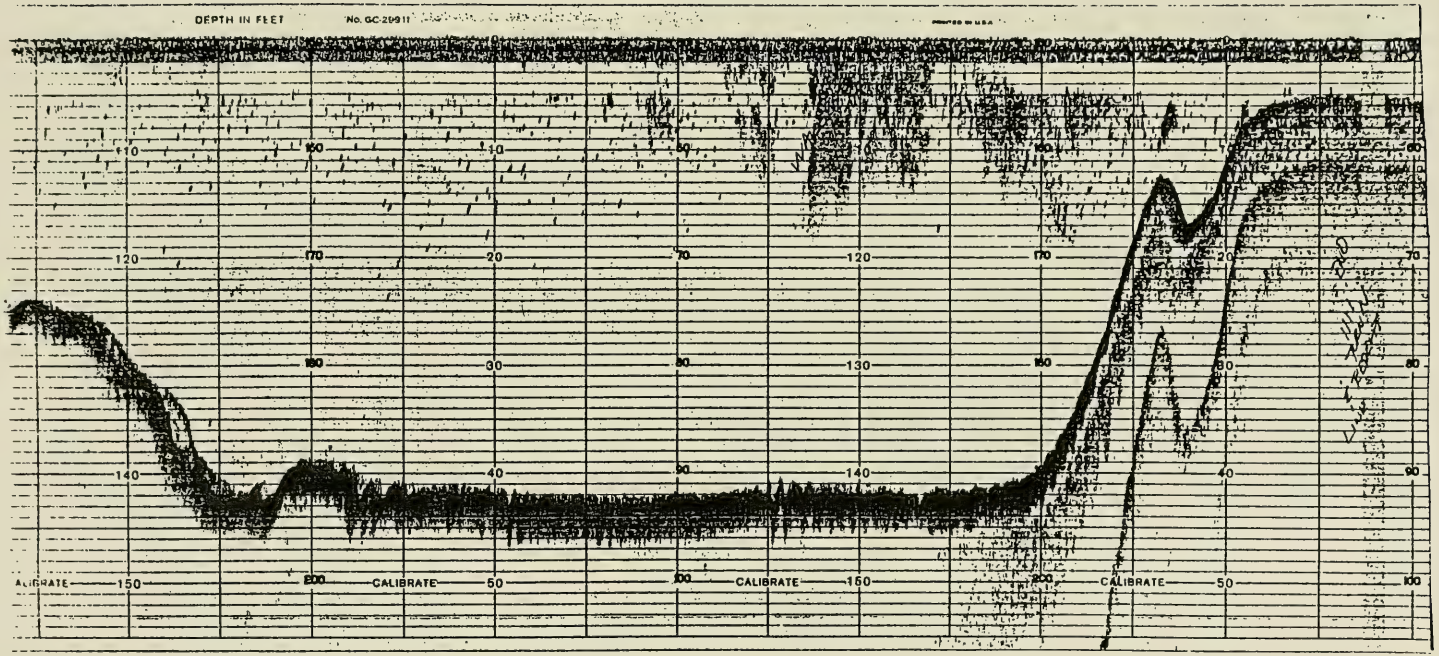
Beginning segment of Transect #3 acoustic survey of 2 November 1993; profile runs east to west



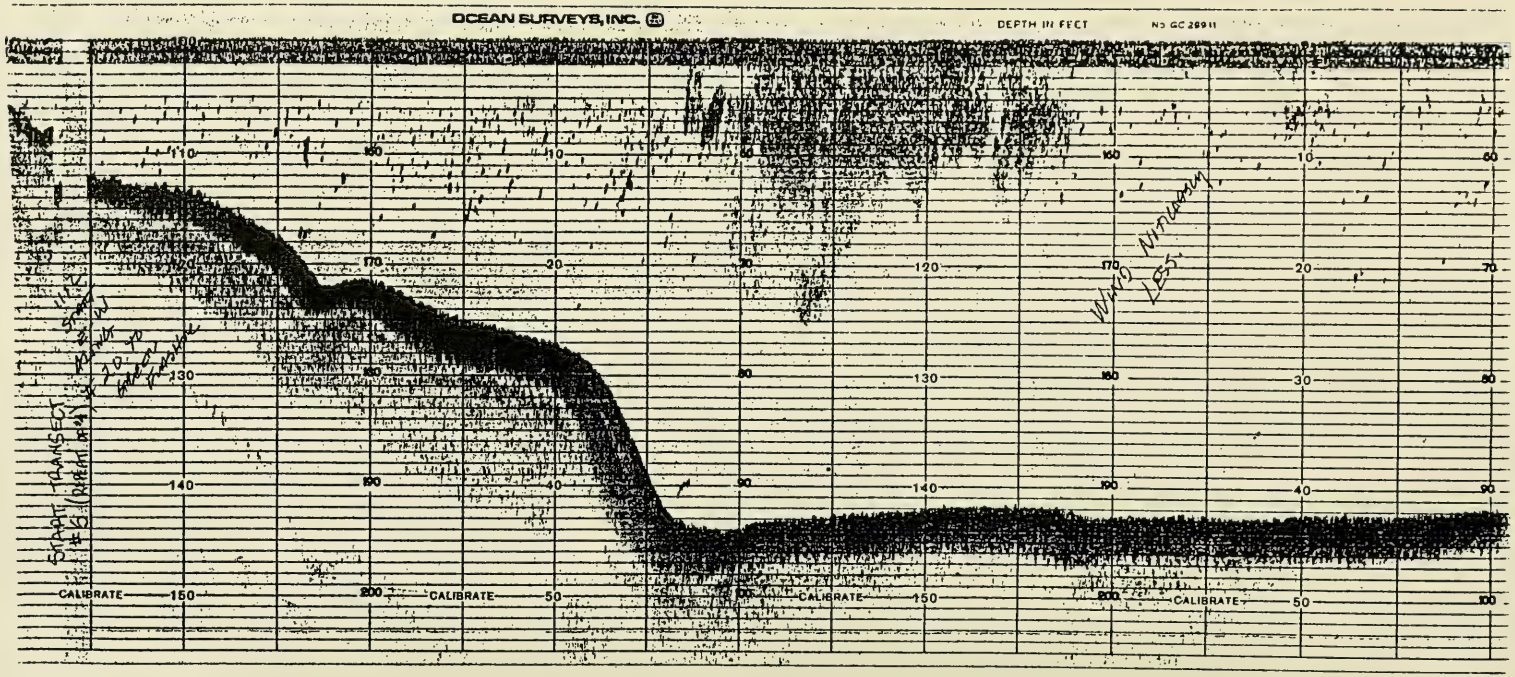
End segment of Transect #3 acoustic survey of 2 November 1993; profile runs east to west



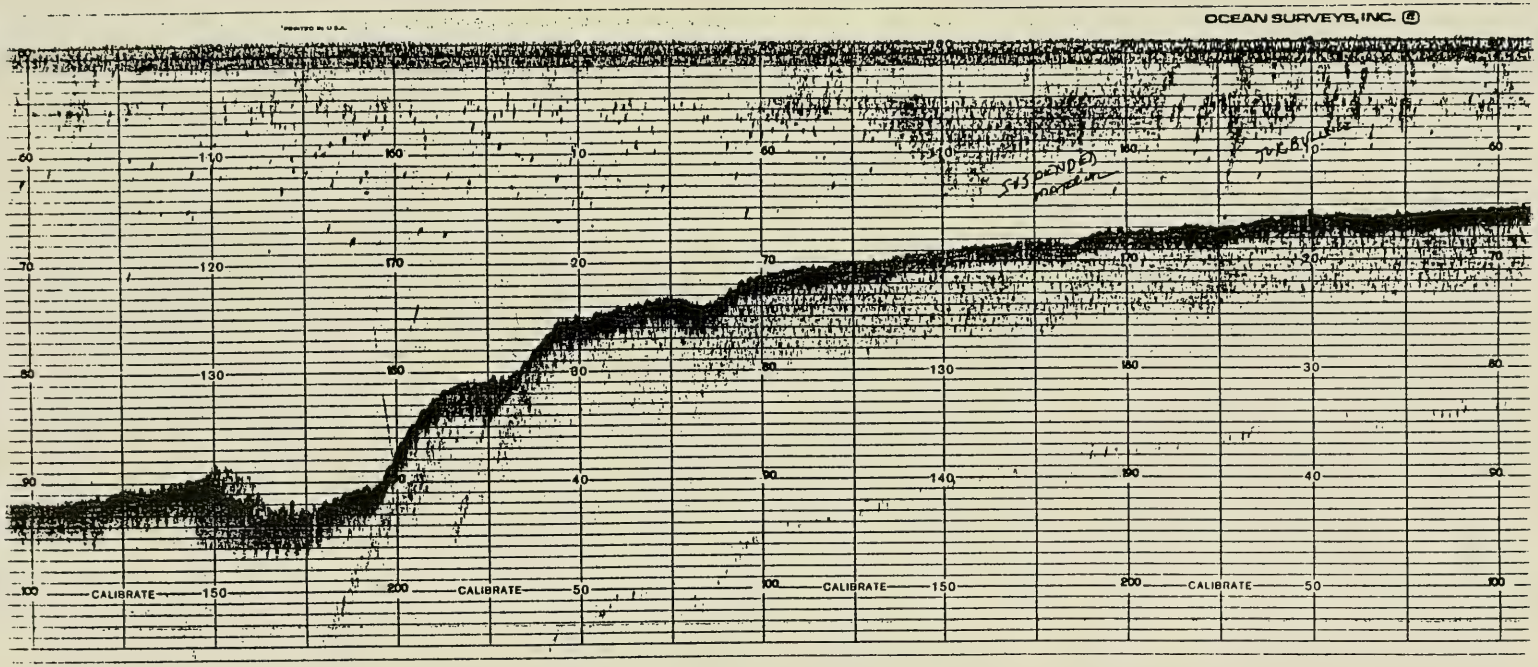
Beginning segment of Transect #4 acoustic survey of 2 November 1993; profile runs west to east



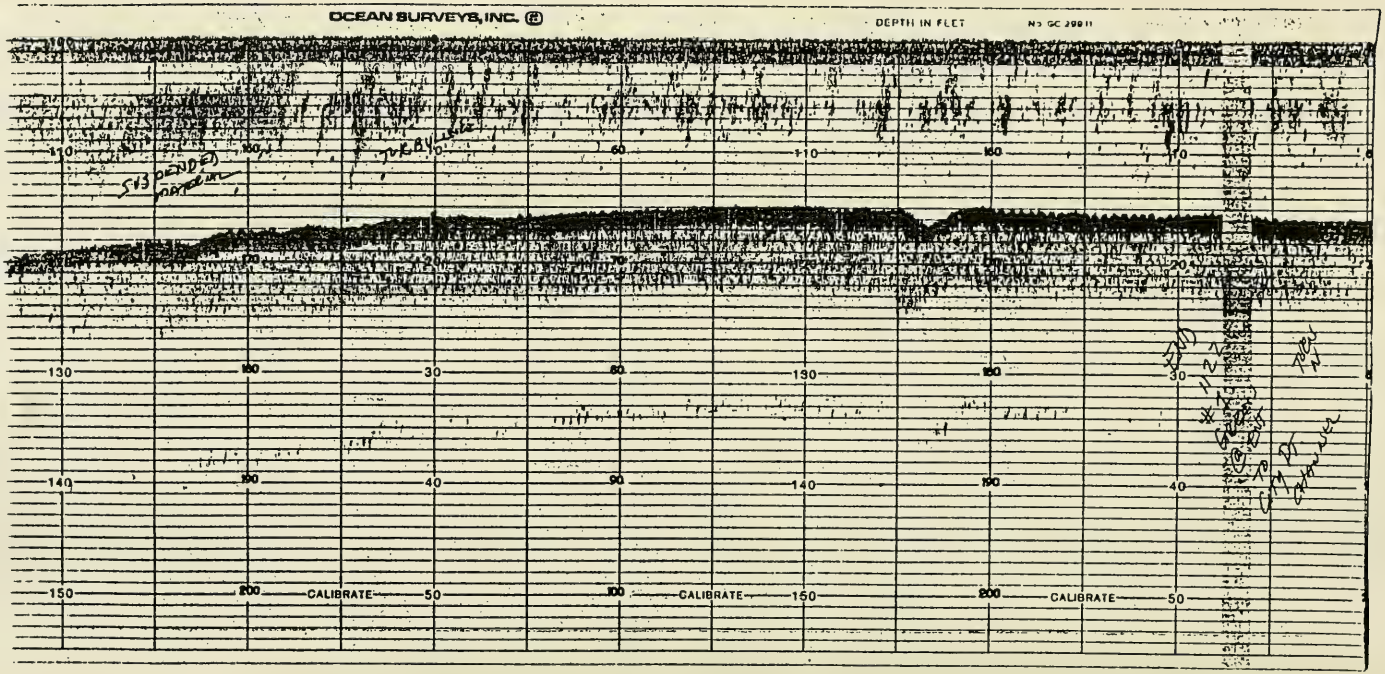
End segment of Transect #4 acoustic survey of 2 November 1993; profile runs west to east



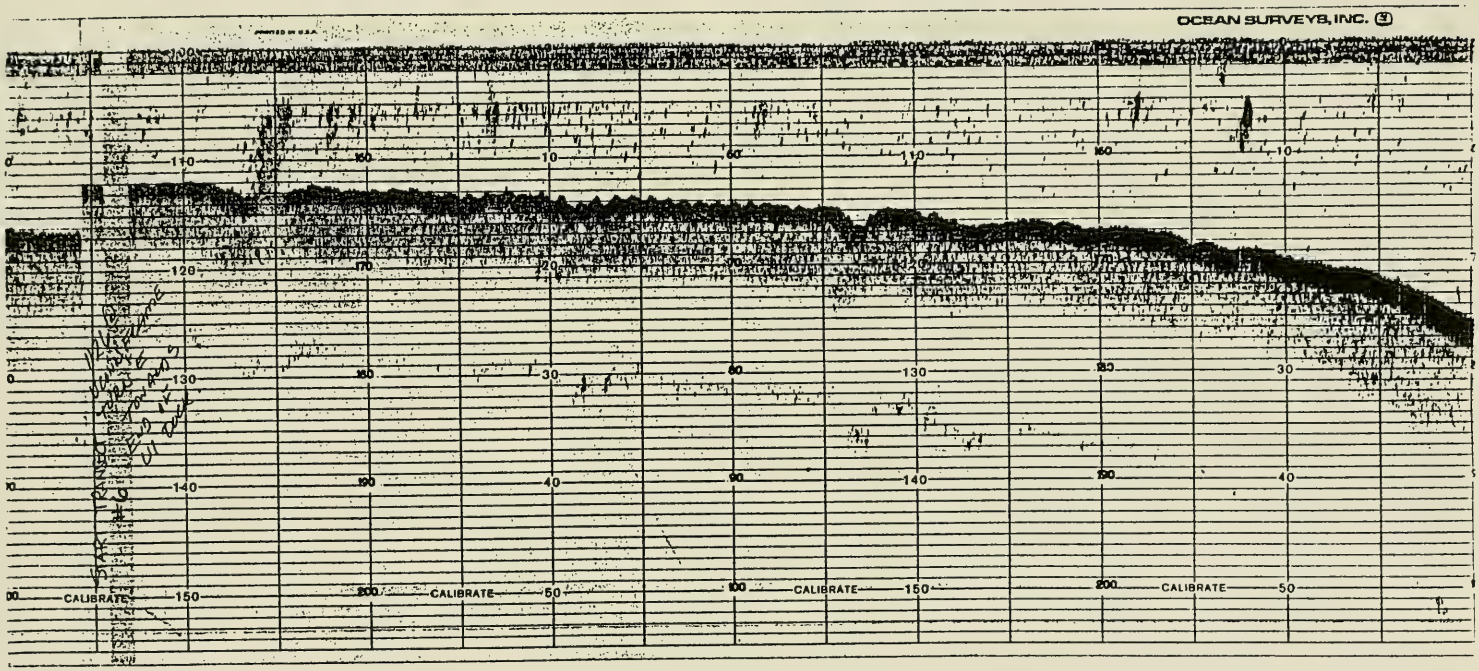
Beginning segment of Transect #5 acoustic survey of 2 November 1993; profile runs east to west



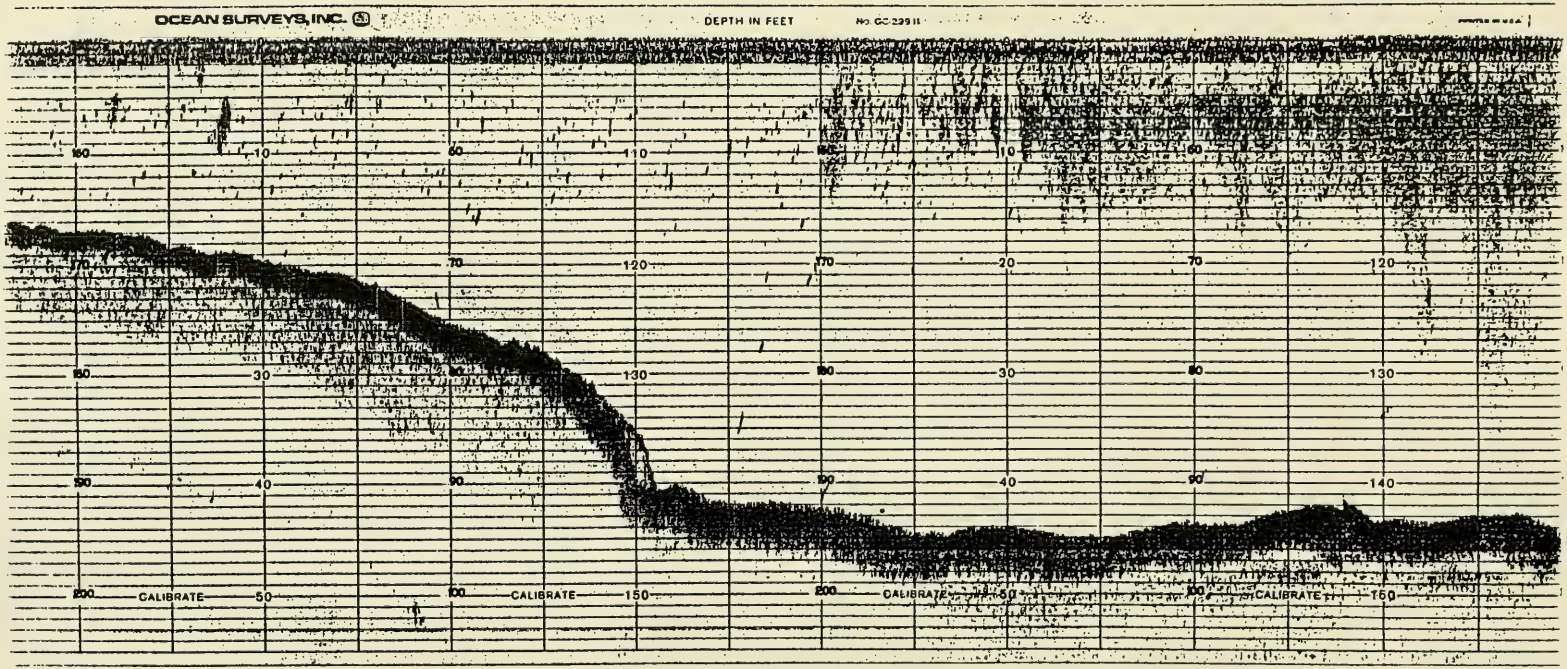
Middle segment of Transect #5 acoustic survey of 2 November 1993; profile runs east to west



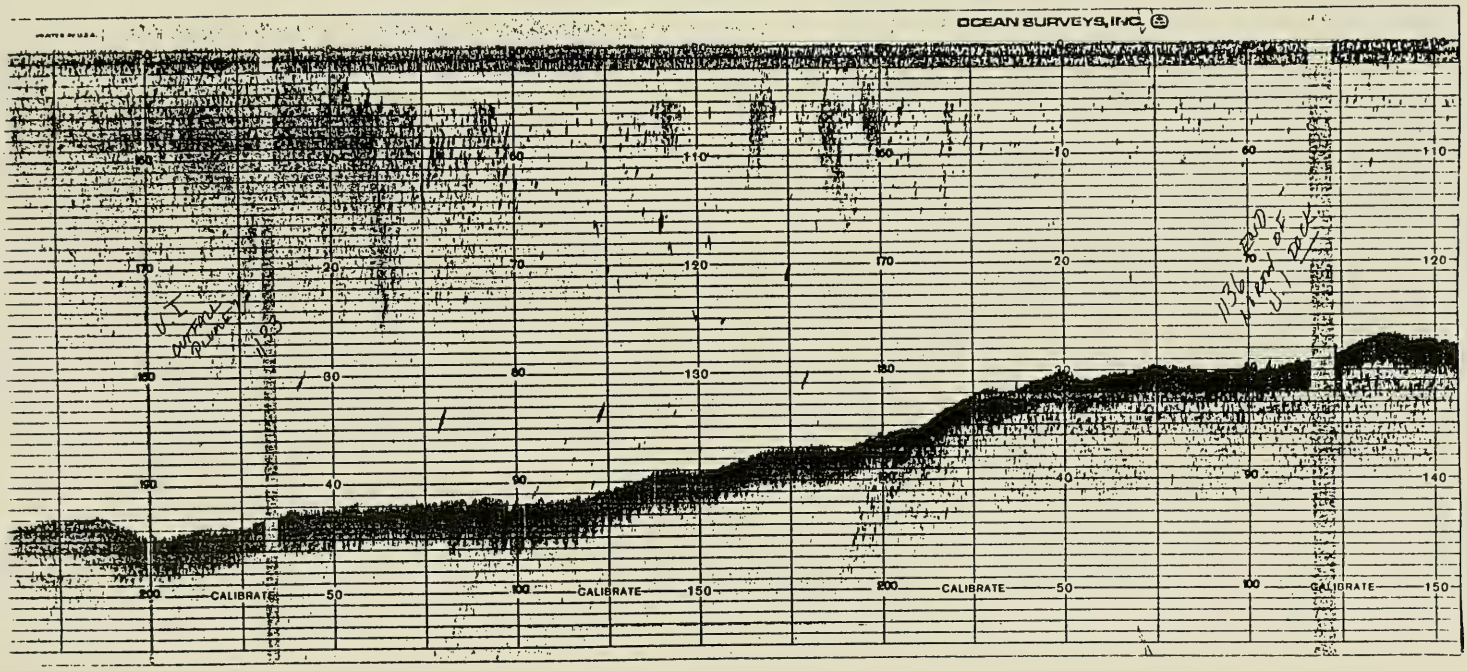
End segment of Transect #5 acoustic survey of 2 November 1993; profile runs east to west



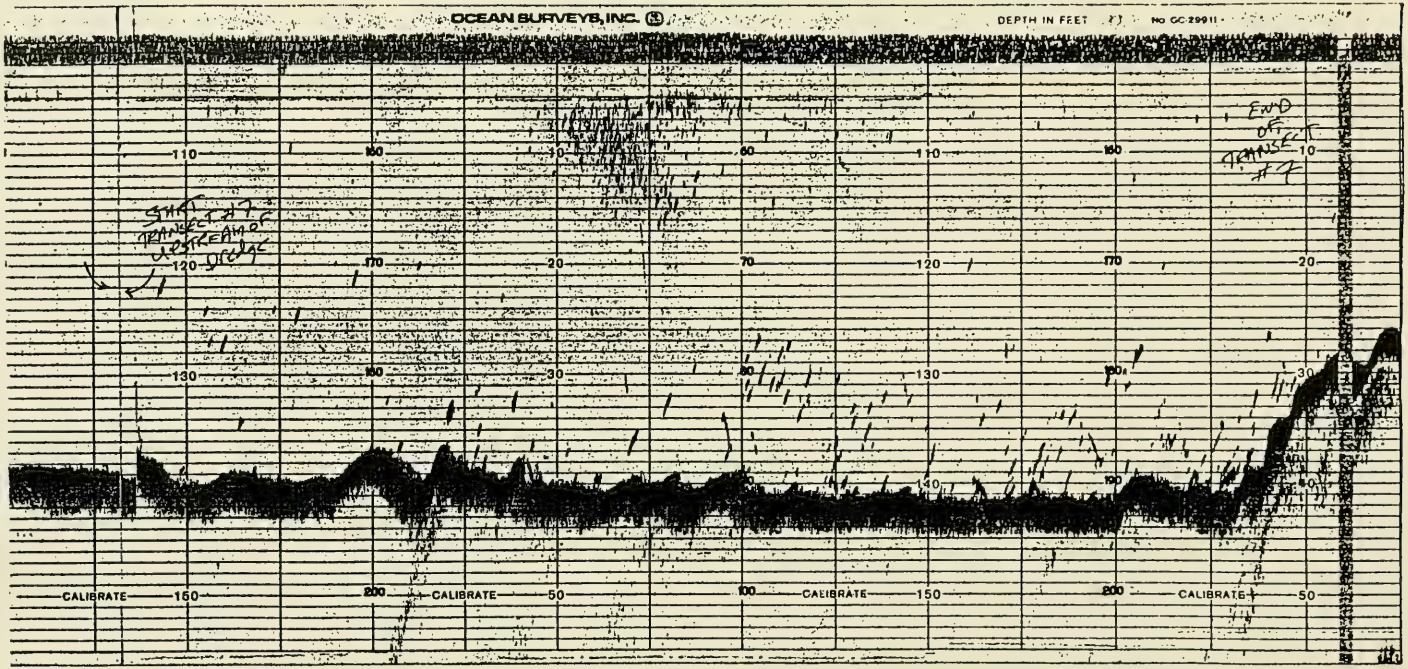
Beginning segment of Transect #6 acoustic survey of 2 November 1993; profile runs west to east



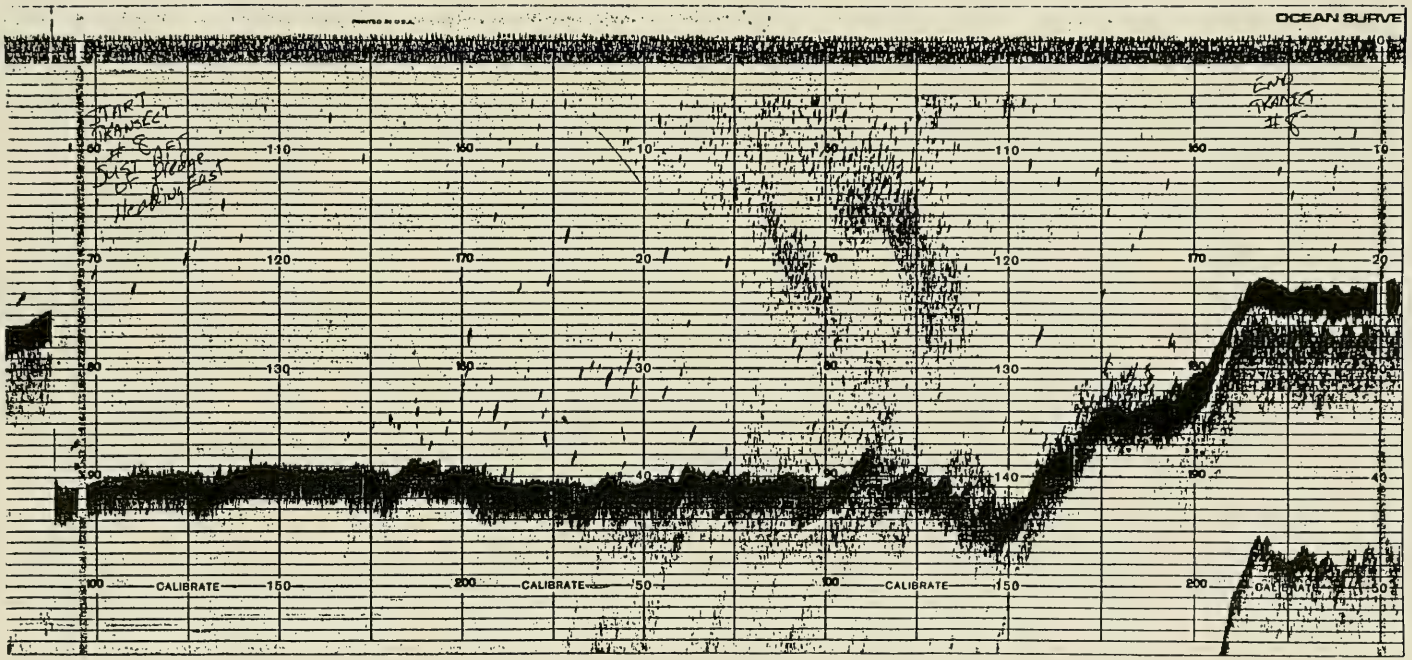
Middle segment of Transect #6 acoustic survey of 2 November 1993; profile runs west to east



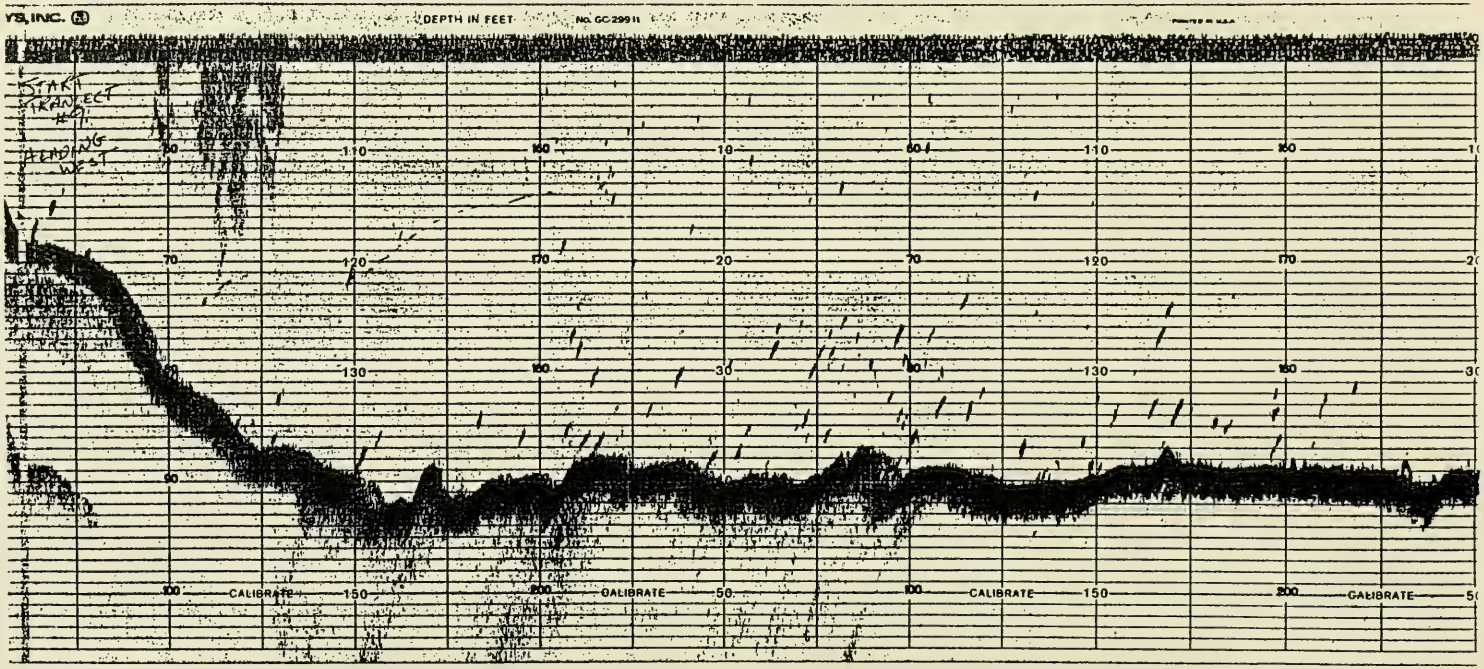
End segment of Transect #6 acoustic survey of 2 November 1993; profile runs west to east



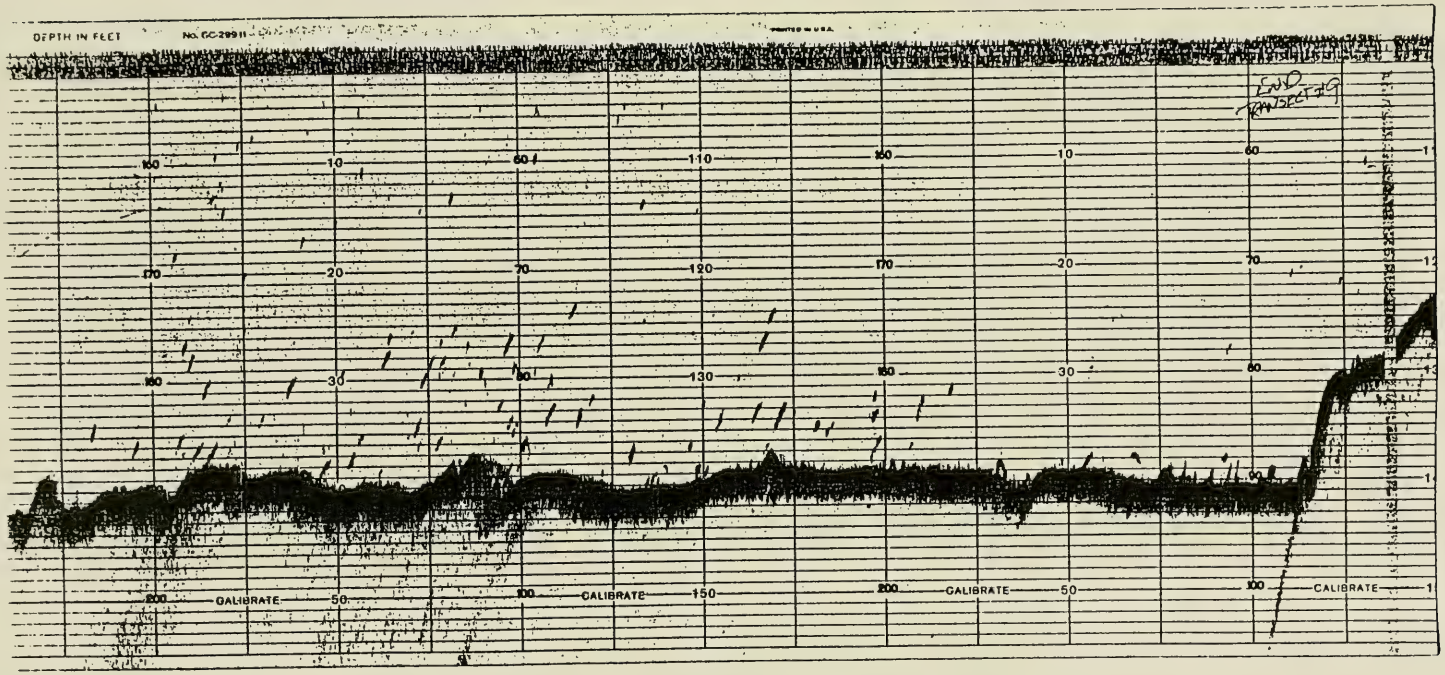
Transect #7 acoustic survey of 2 November 1993; profile runs east to west



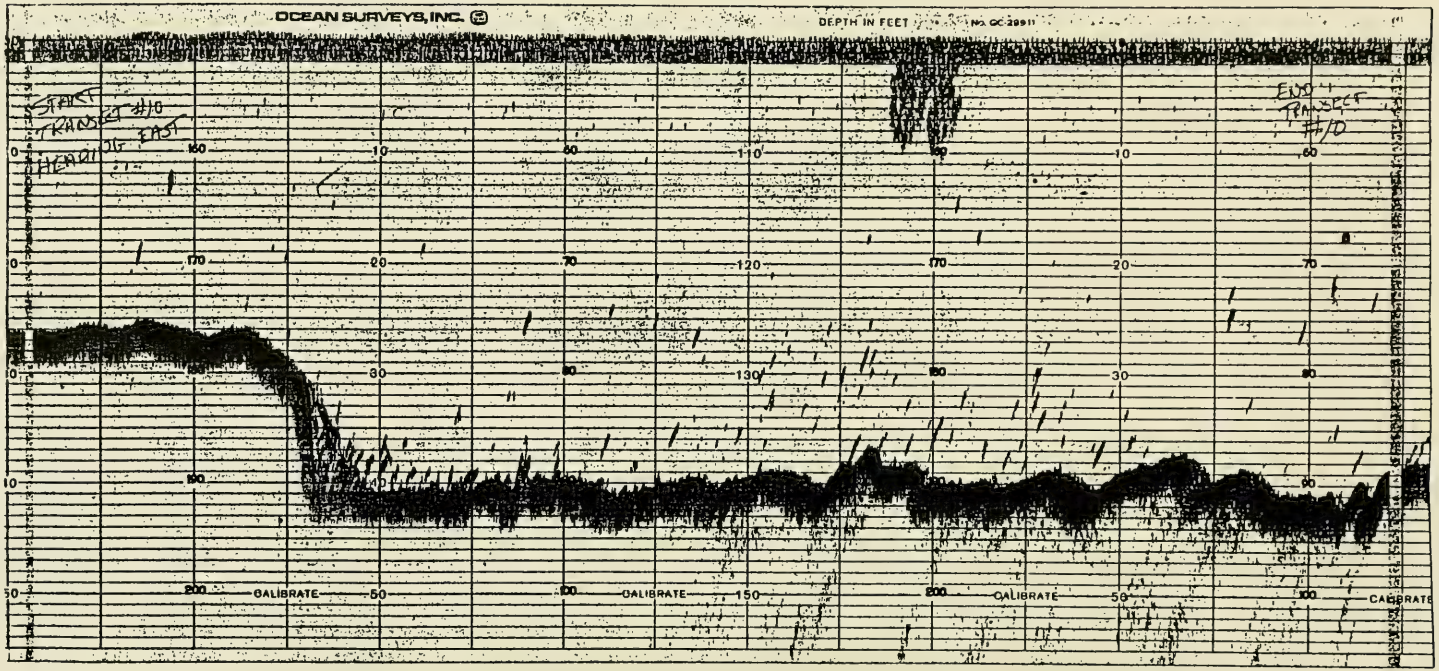
Transect #8 acoustic survey of 2 November 1993; profile runs west to east



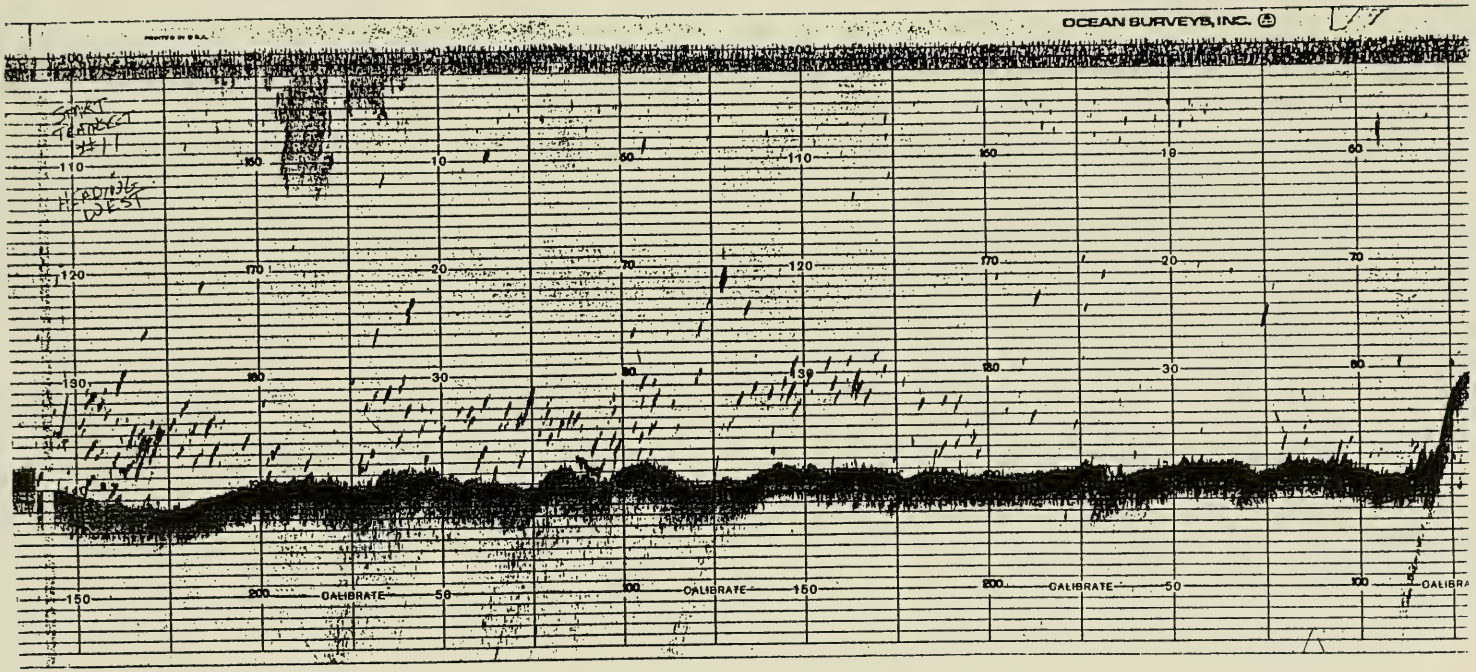
Beginning segment of Transect #9 acoustic survey of 2 November 1993; profile runs east to west



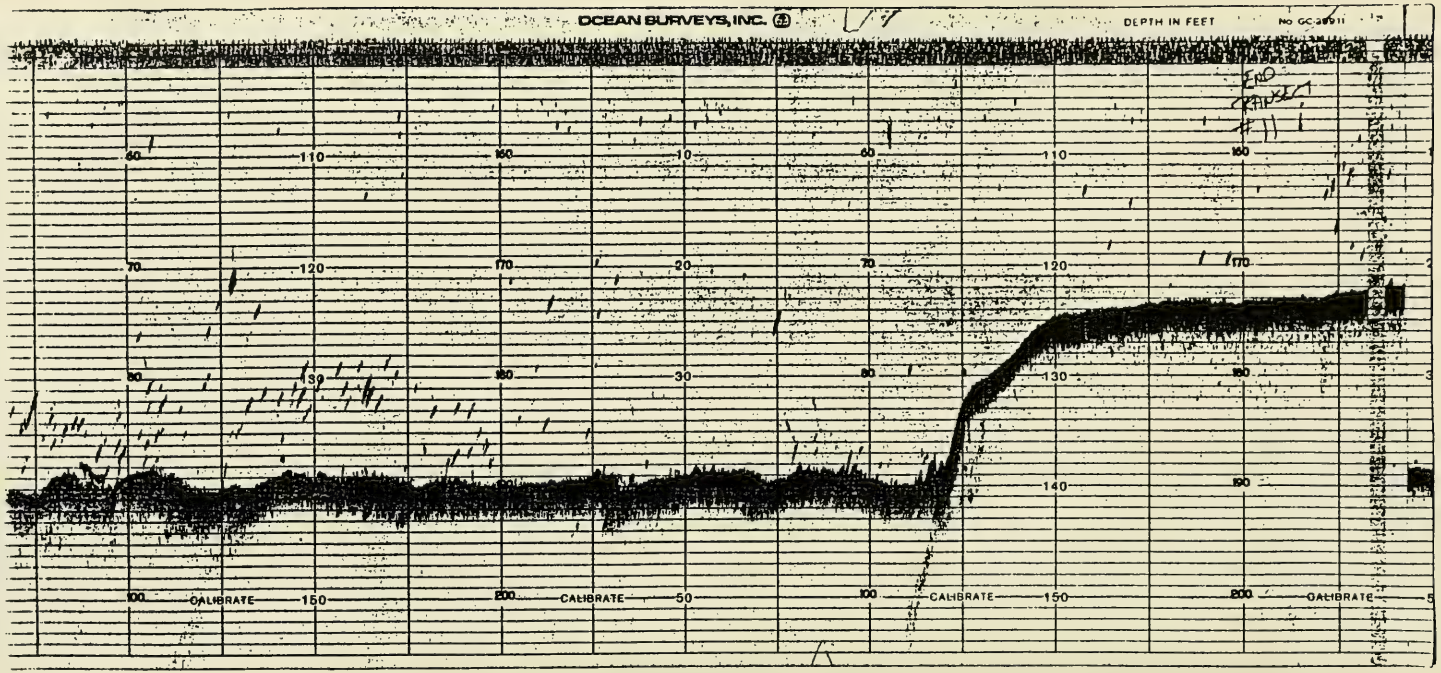
End segment of Transect #9 acoustic survey of 2 November 1993; profile runs east to west



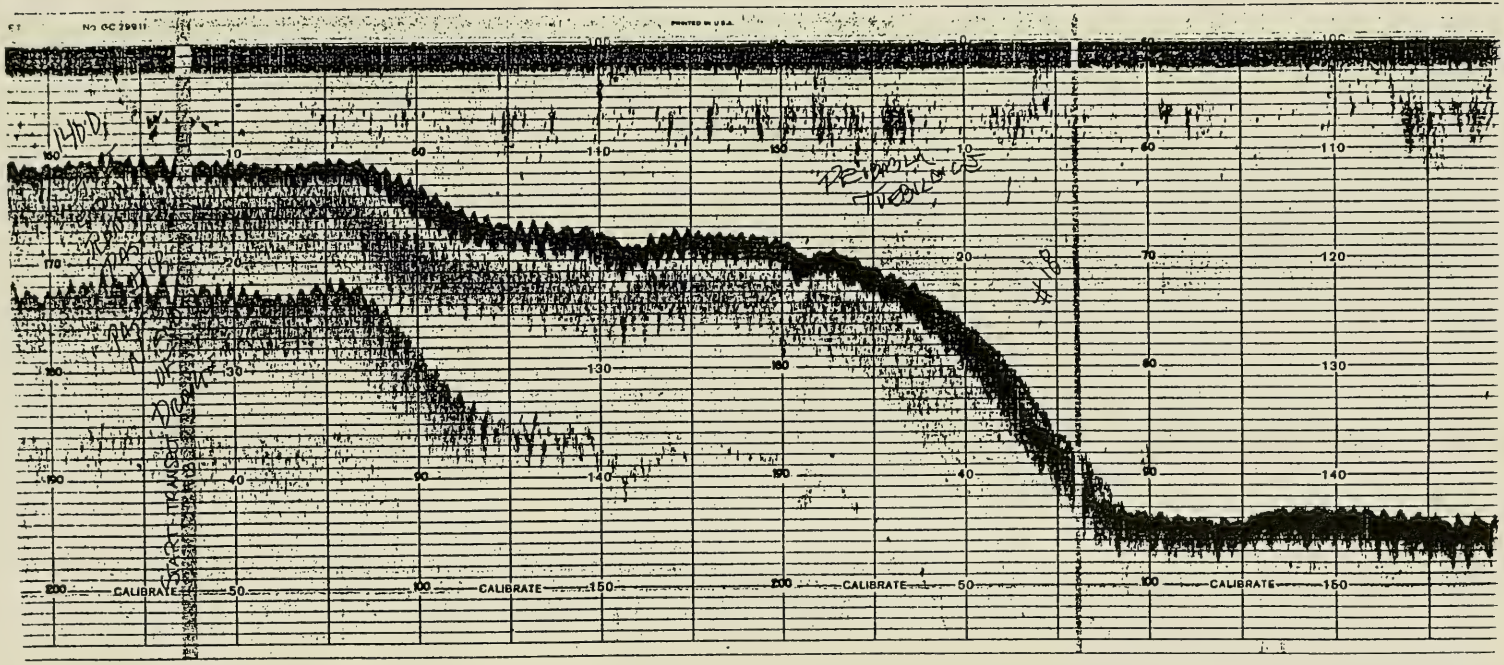
Transect #10 acoustic survey of 2 November 1993; profile runs west to east



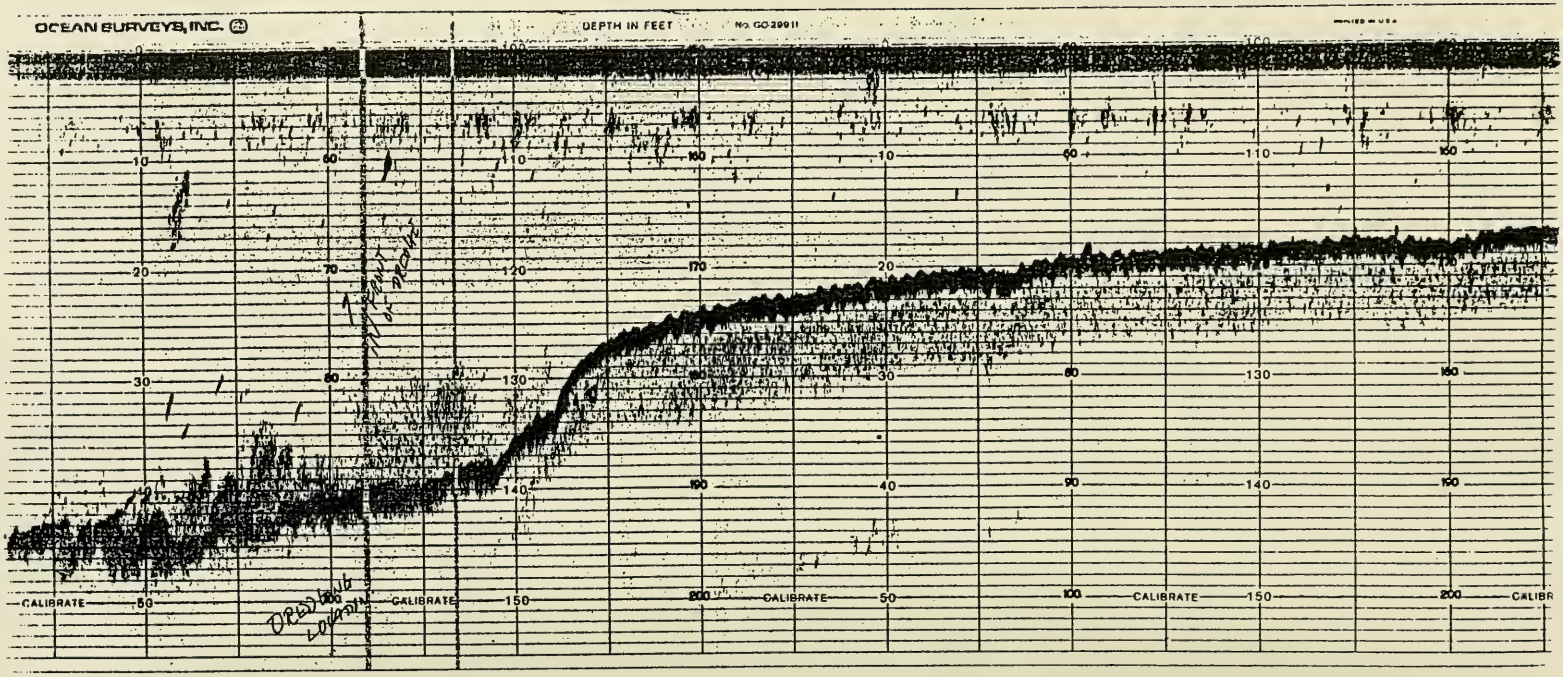
Beginning segment of Transect #11 acoustic survey of 2 November 1993; profile runs east to west



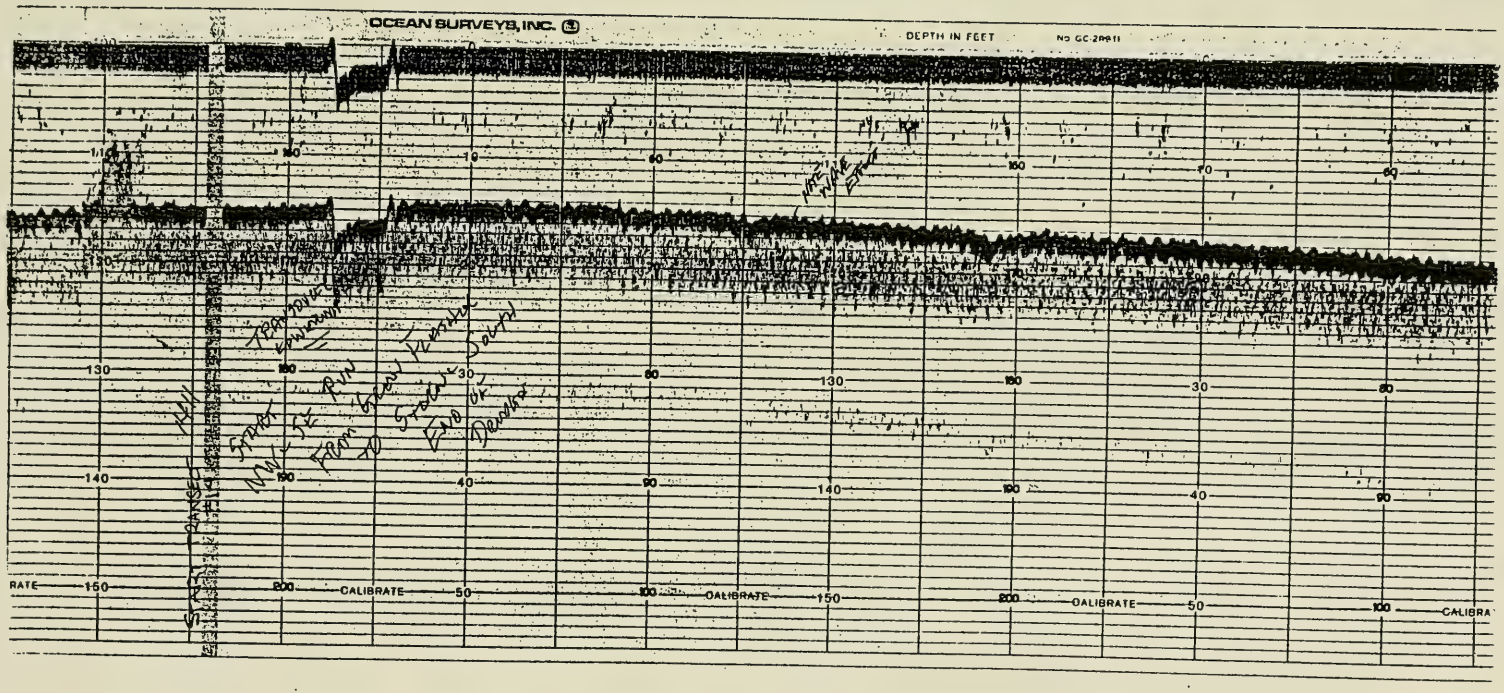
End segment of Transect #11 acoustic survey of 2 November 1993; profile east to west



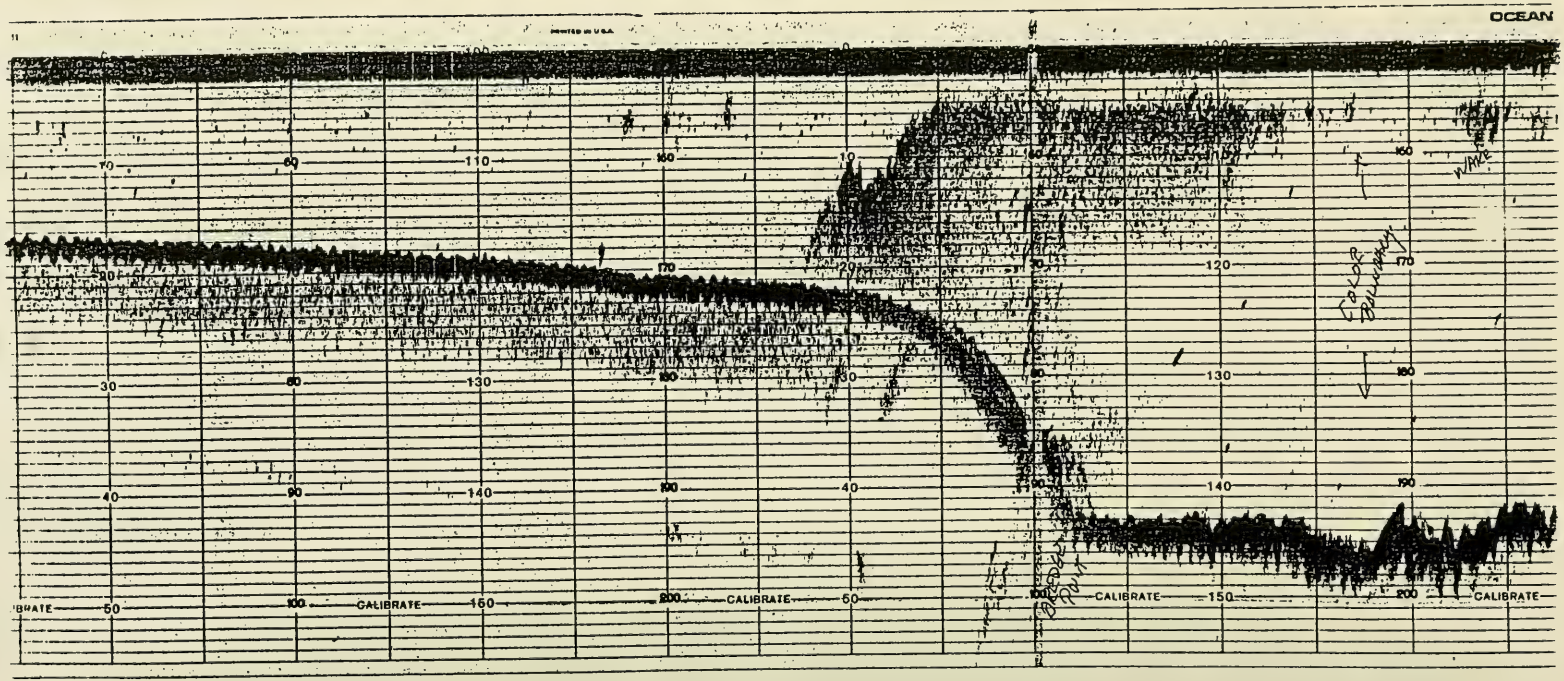
Beginning segment of Transect #13 acoustic survey of 3 November 1993; profile runs east to west



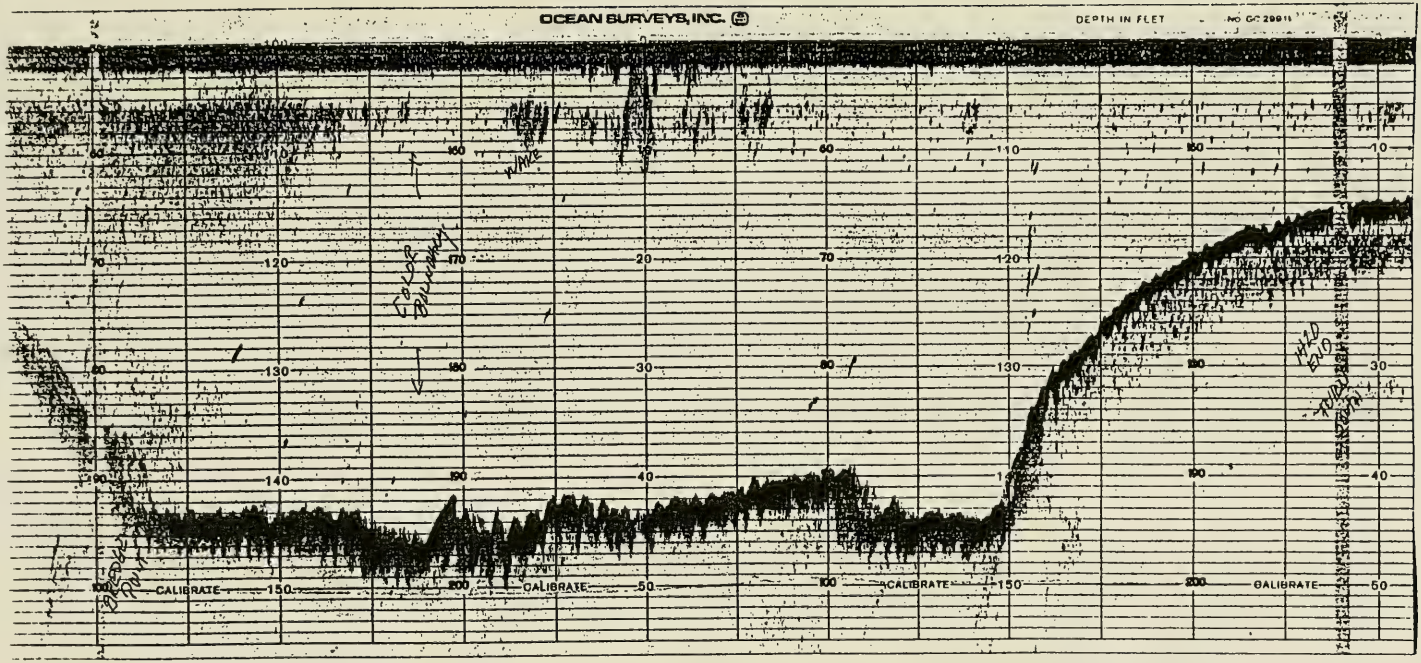
End segment of Transect #13 acoustic survey of 3 November 1993; profile runs east to west



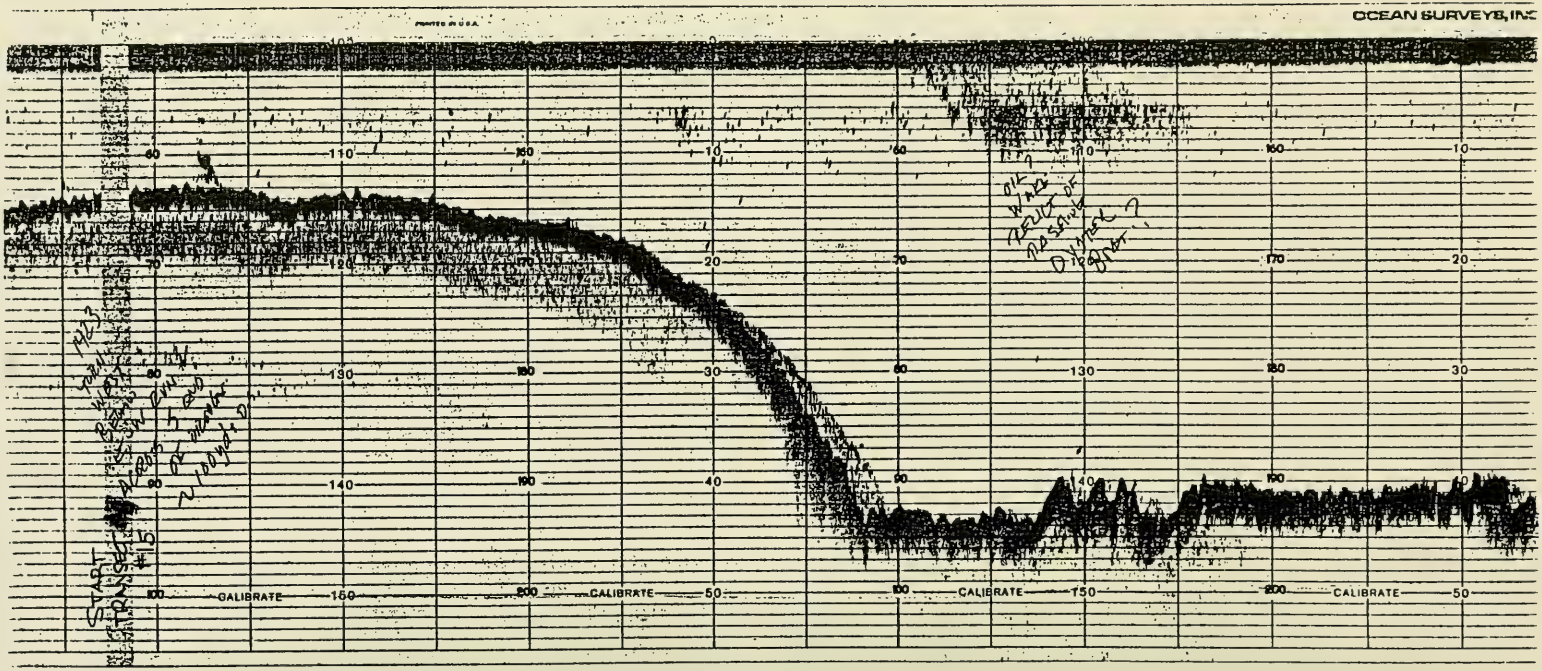
Beginning segment of Transect #14 acoustic survey of 3 November 1993; profile runs northwest to southeast



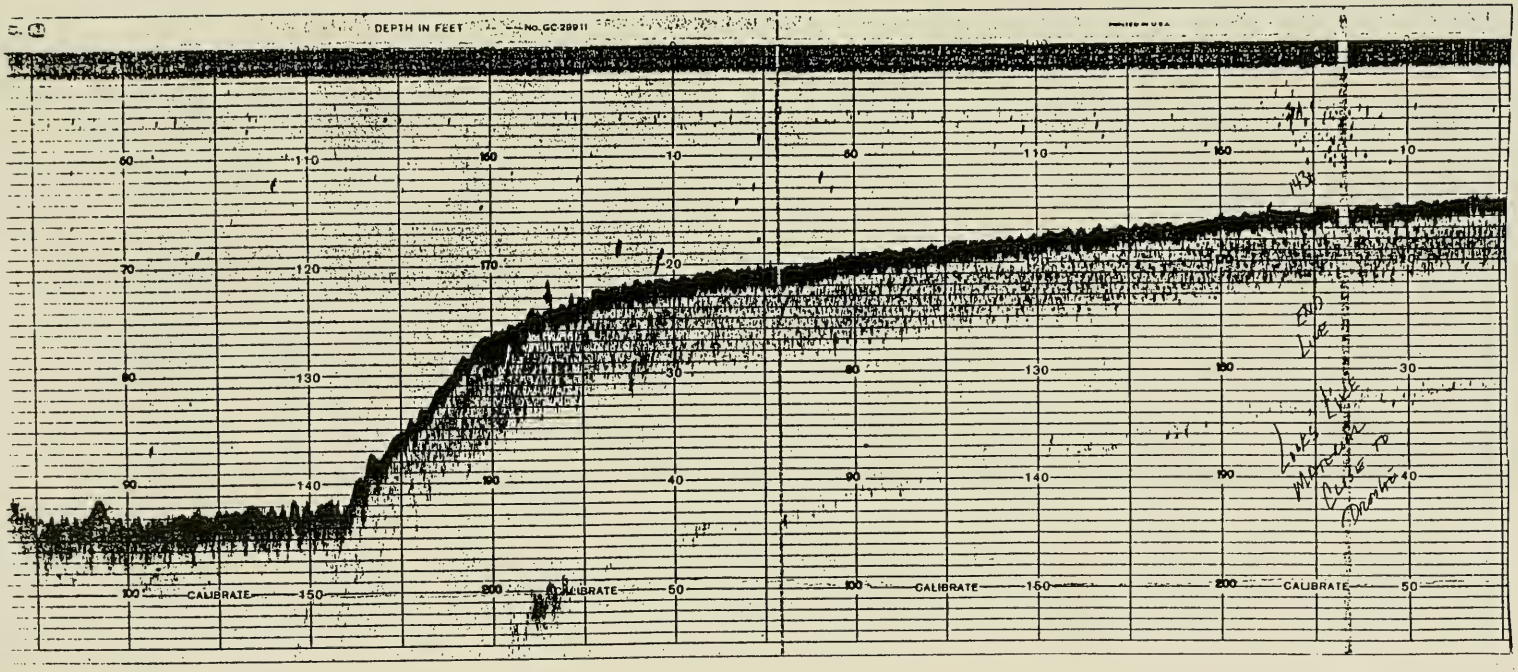
Middle segment of Transect #14 acoustic survey of 3 November 1993; profile runs northwest to southeast



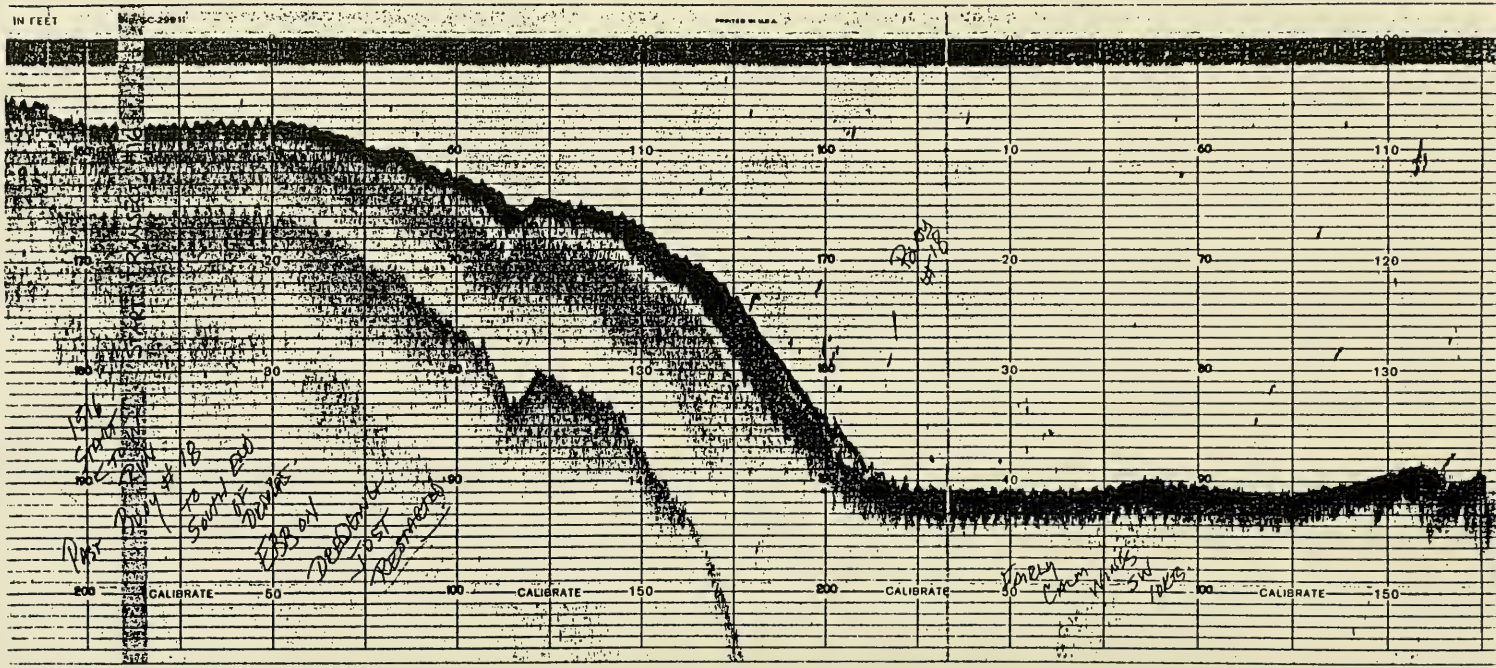
End segment of Transect #14 acoustic survey of 3 November 1993; profile runs northwest to southeast



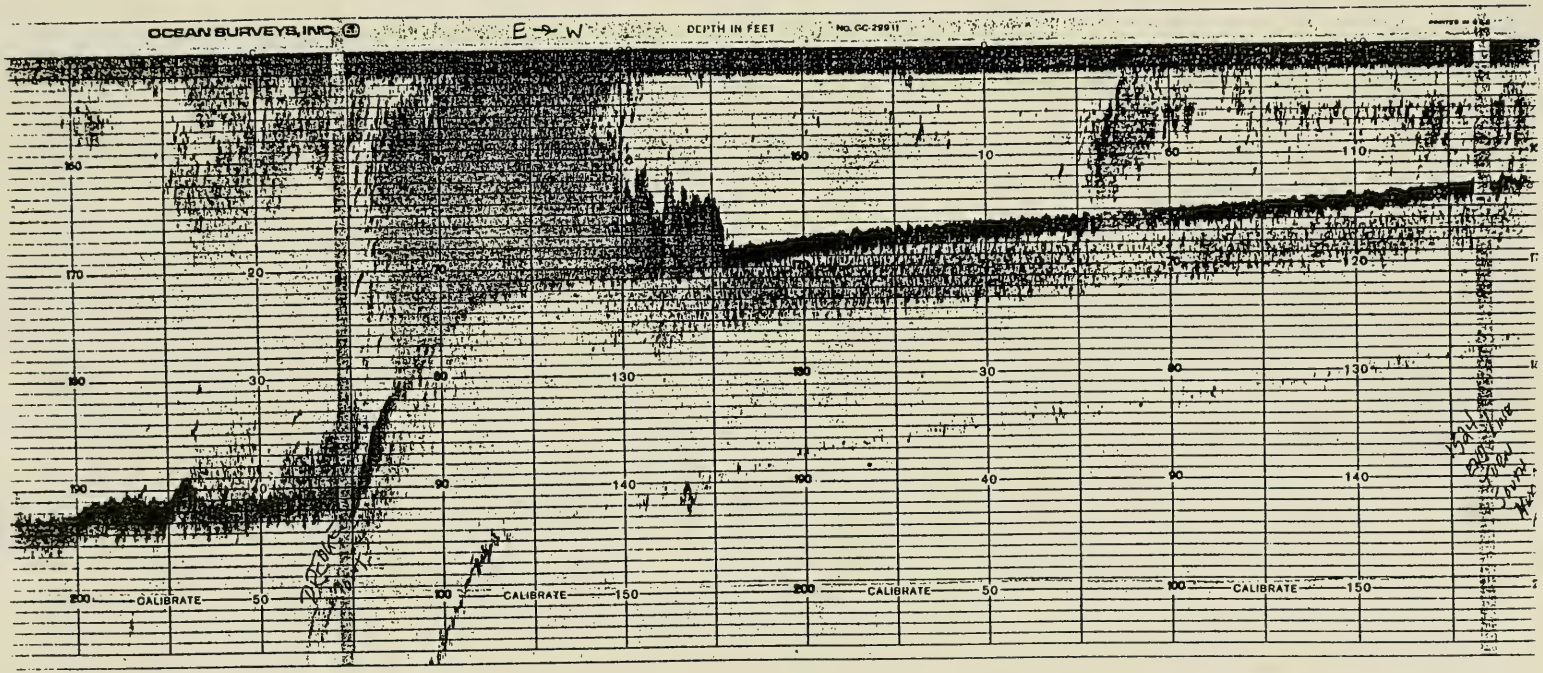
Beginning segment of Transect #15 acoustic survey of 3 November 1993; profile runs east to west



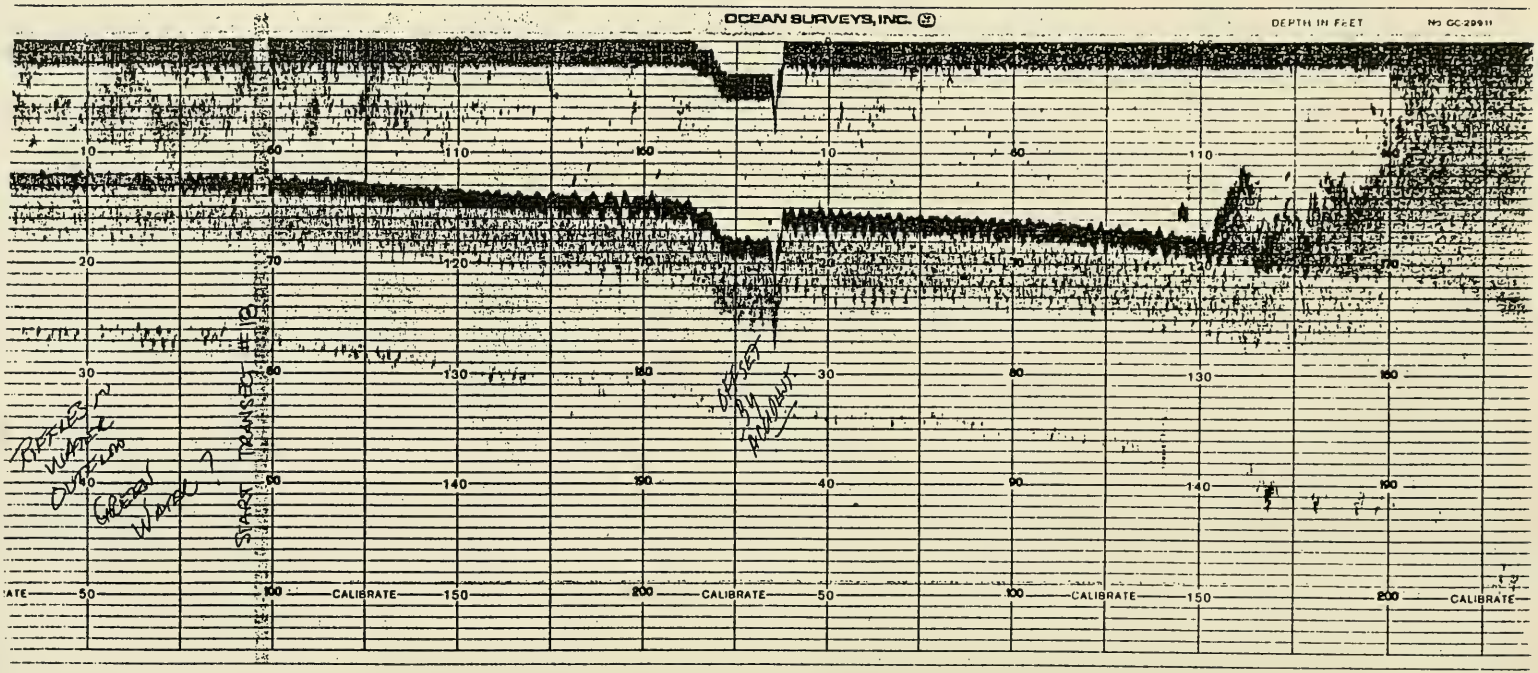
End segment of Transect #15 acoustic survey of 3 November 1993; profile runs east to west



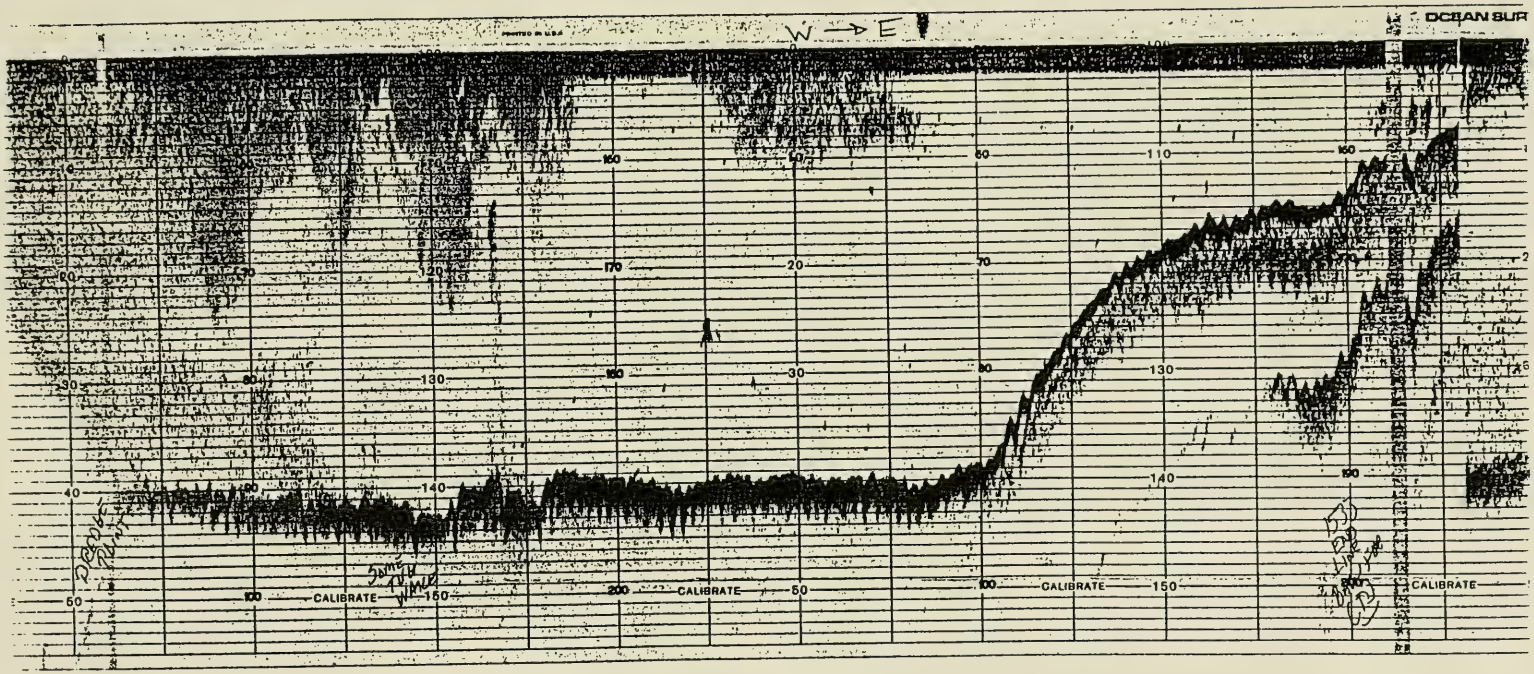
Beginning segment of Transect #16 acoustic survey of 3 November 1993; profile runs east to west



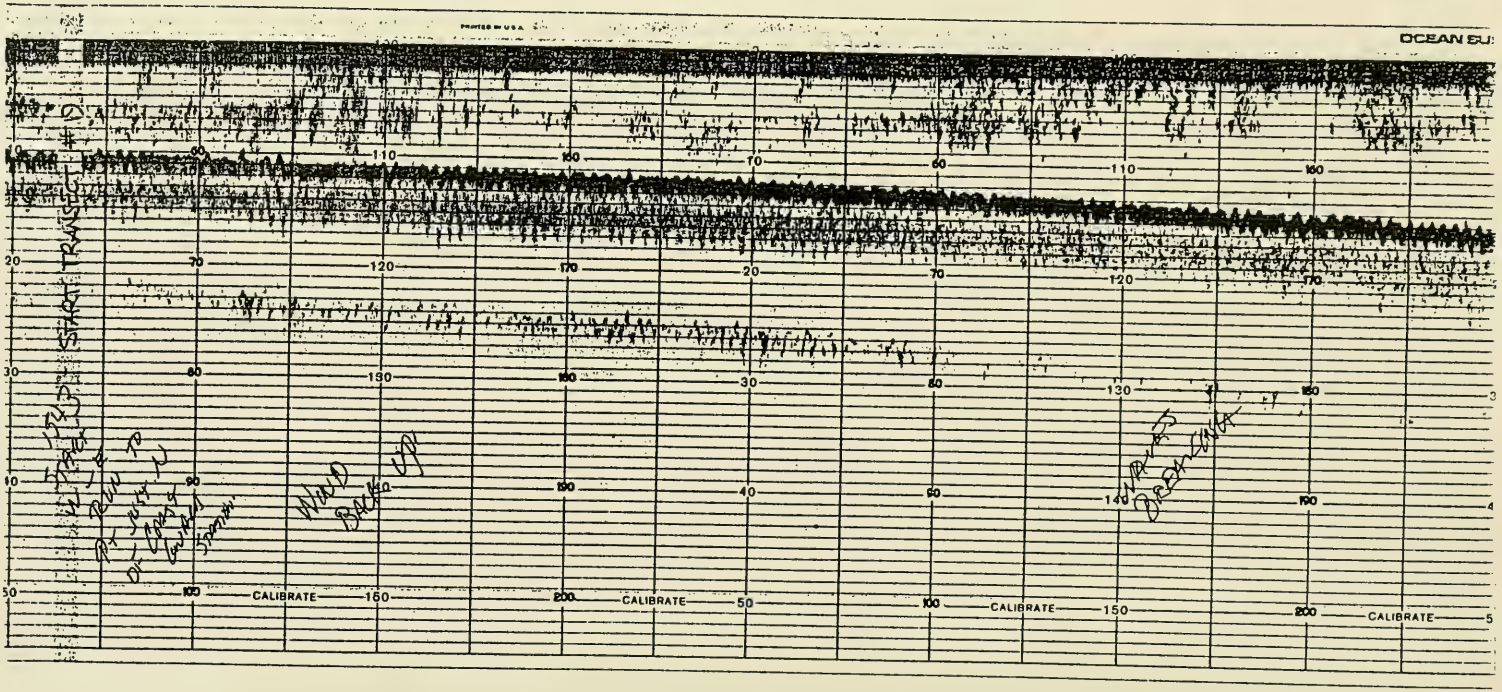
End segment of Transect #16 acoustic survey of 3 November 1993; profile runs east to west



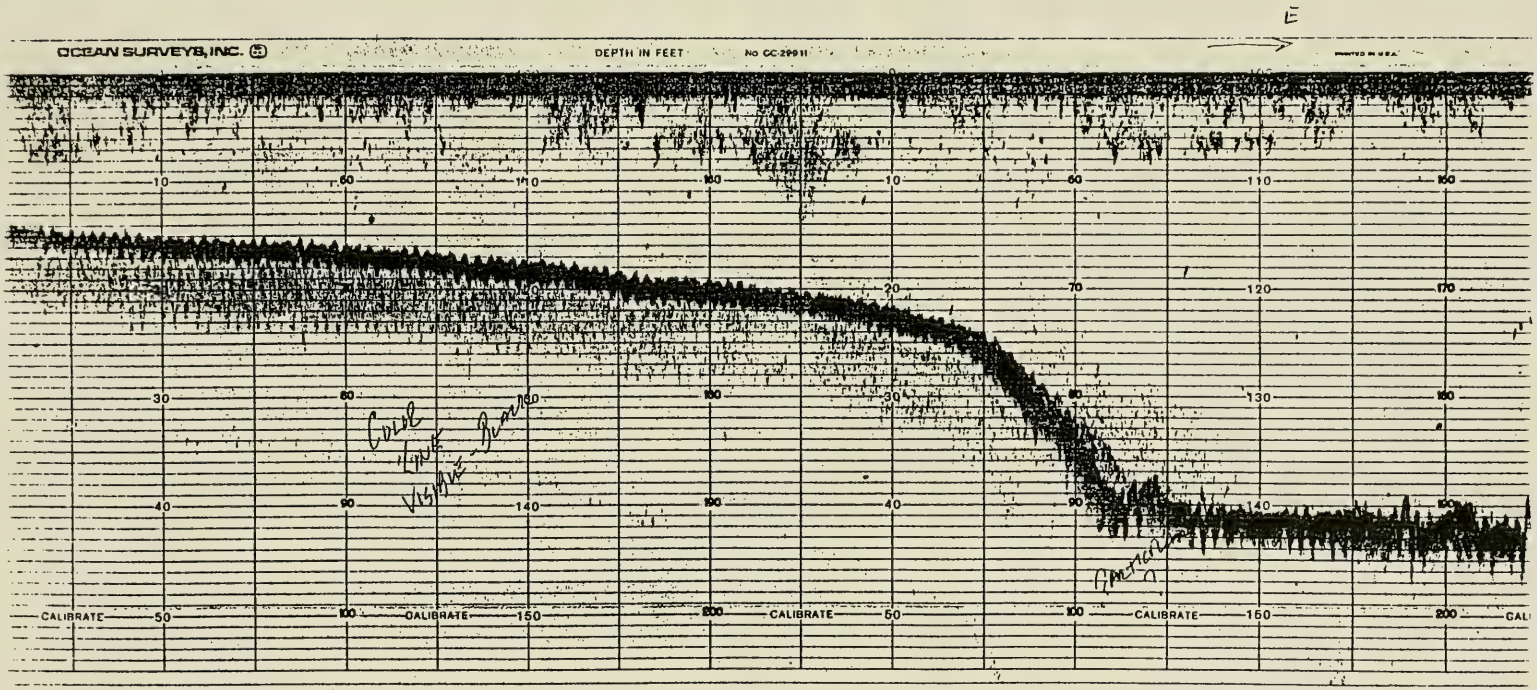
Beginning segment of Transect #18 acoustic survey of 3 November 1993; profile runs west to east



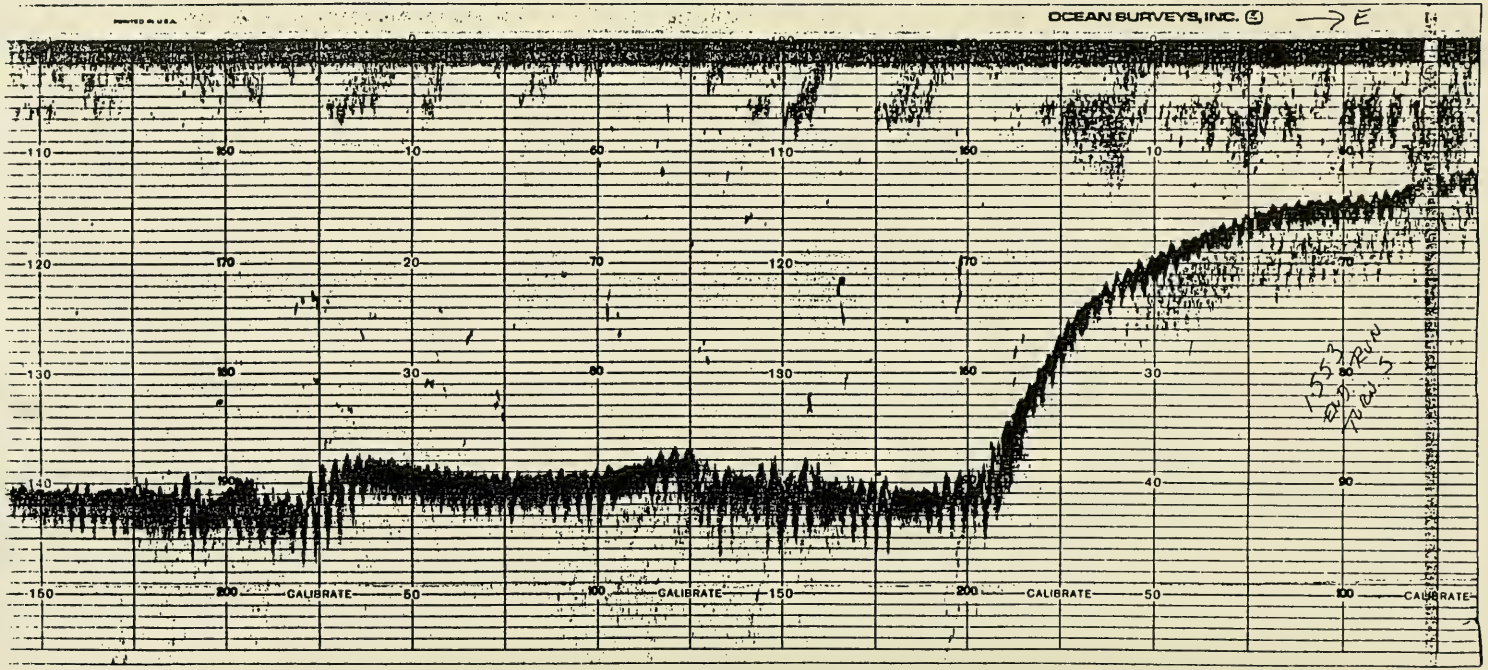
End segment of Transect #18 acoustic survey of 3 November 1993; profile runs west to east



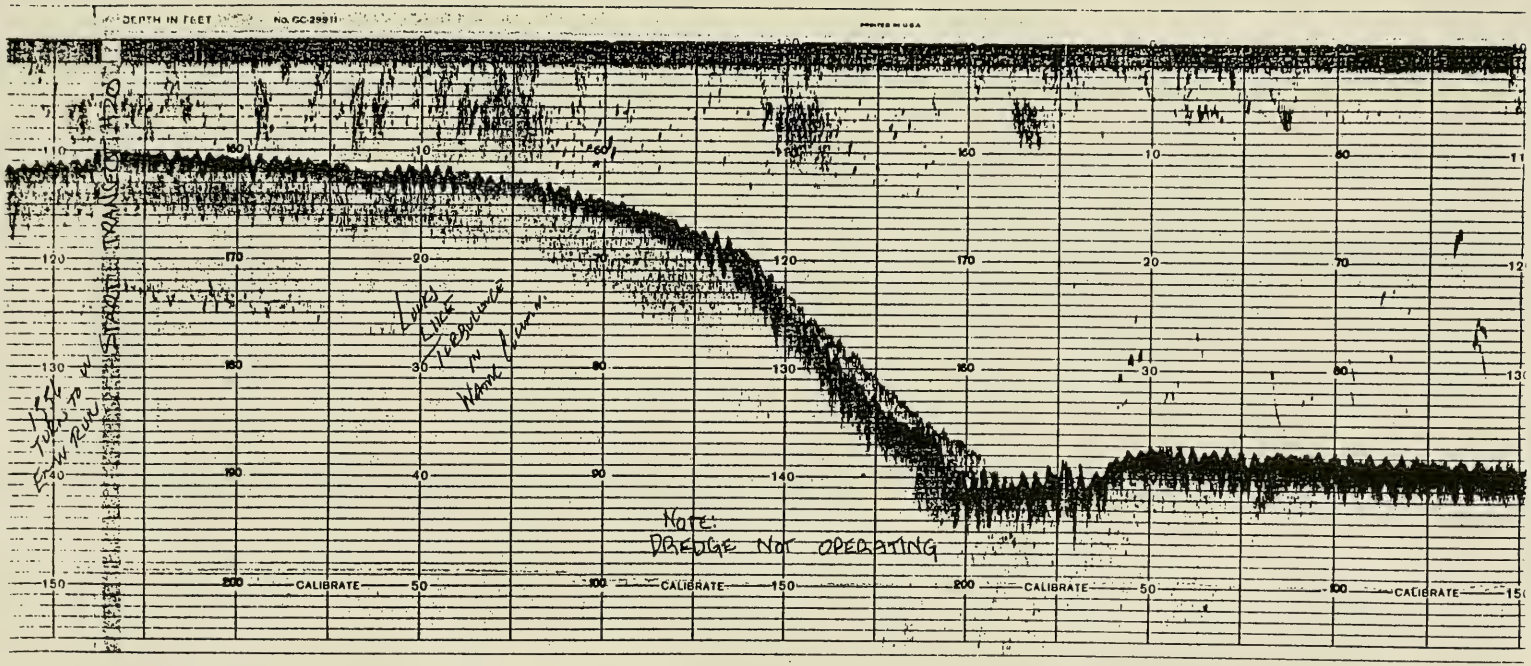
Beginning segment of Transect #19 acoustic survey of 3 November 1993; profile runs west to east



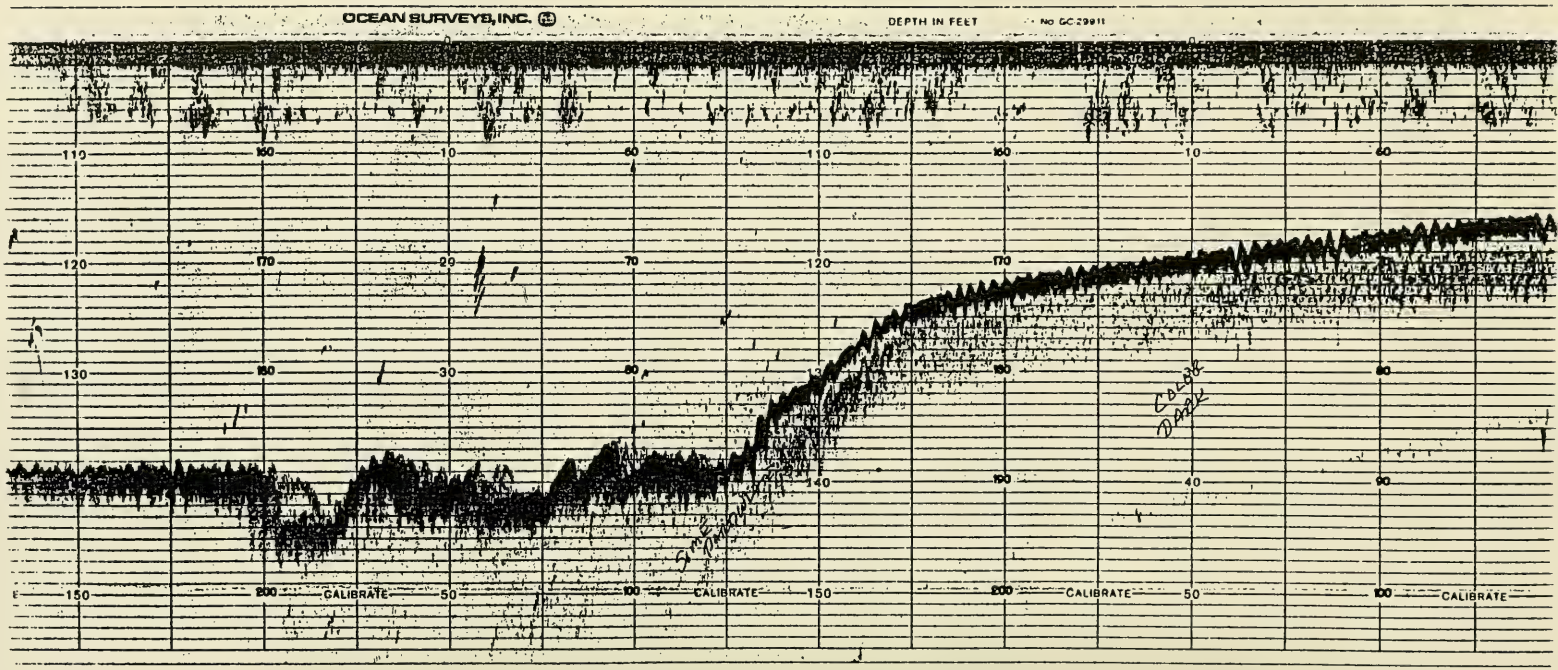
Middle segment of Transect #19 acoustic survey of 3 November 1993; profile runs west to east



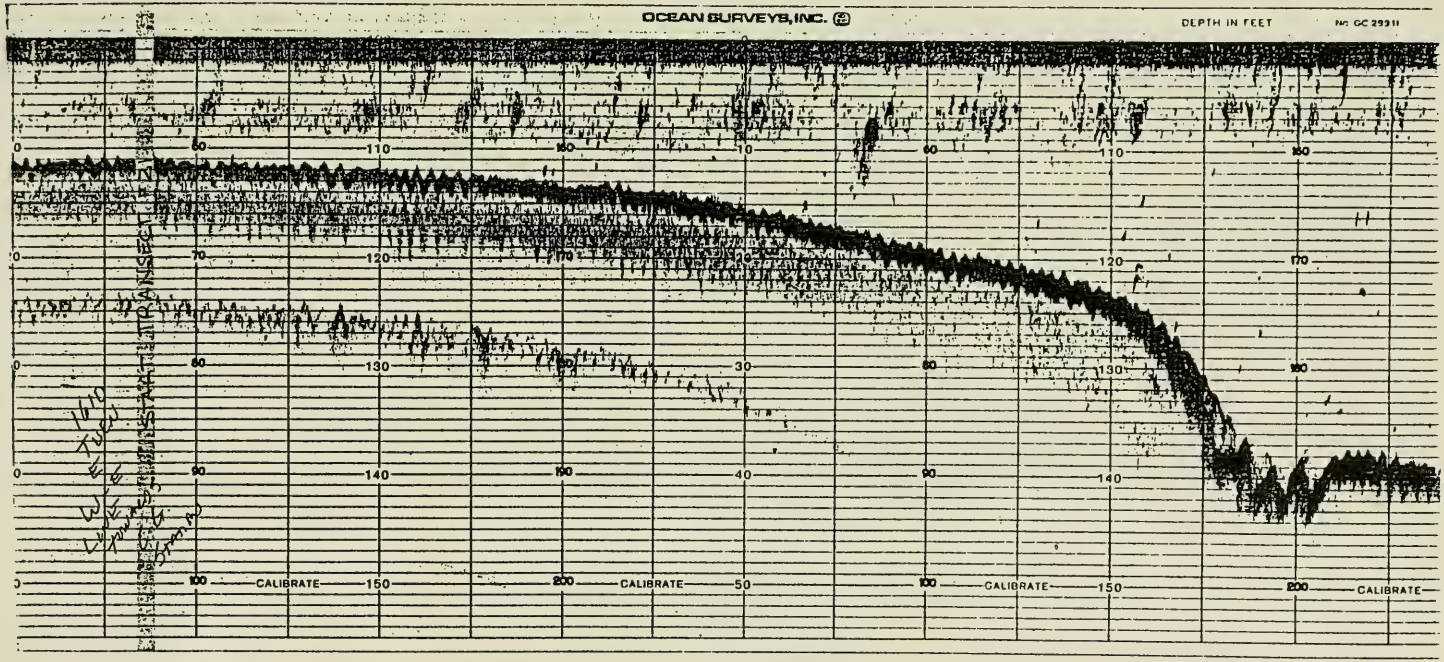
End segment of Transect #19 acoustic survey of 3 November 1993; profile runs west to east



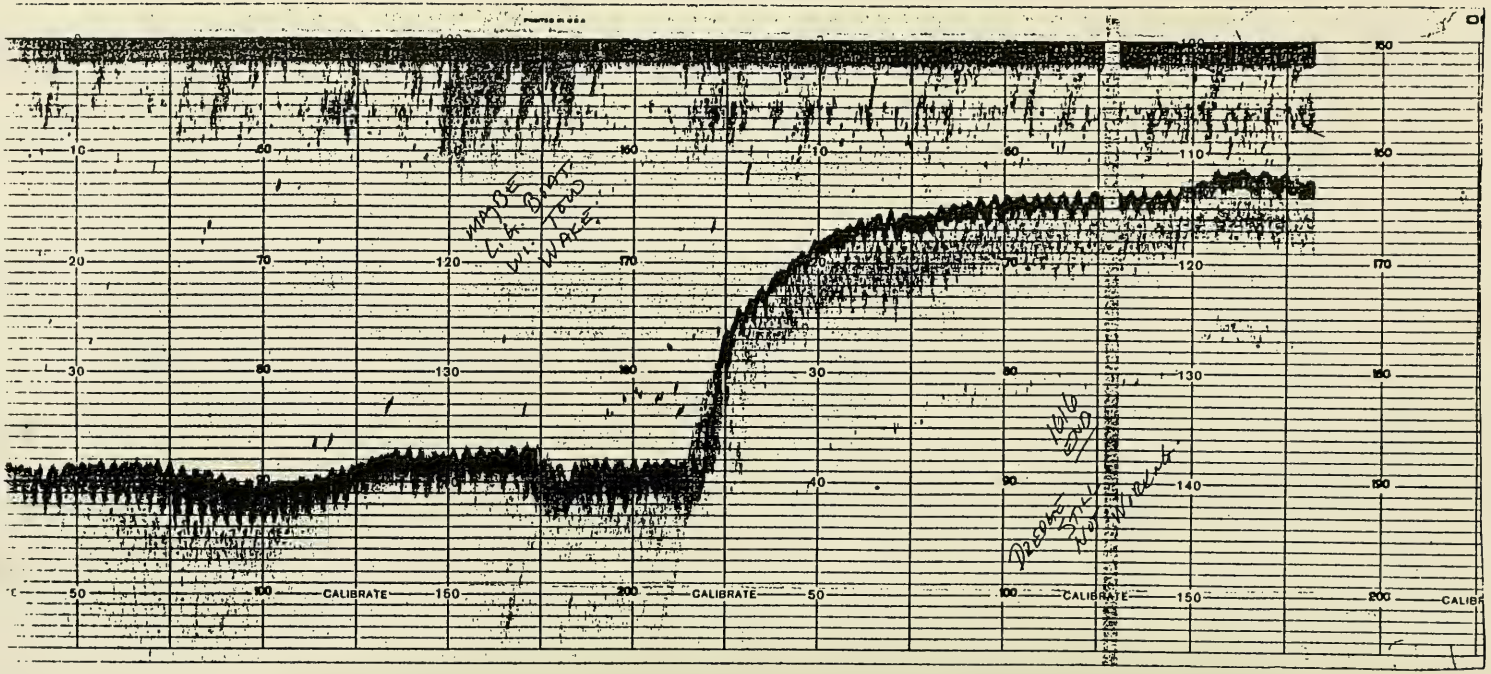
Beginning segment of Transect #20 acoustic survey of 3 November 1993; profile runs east to west



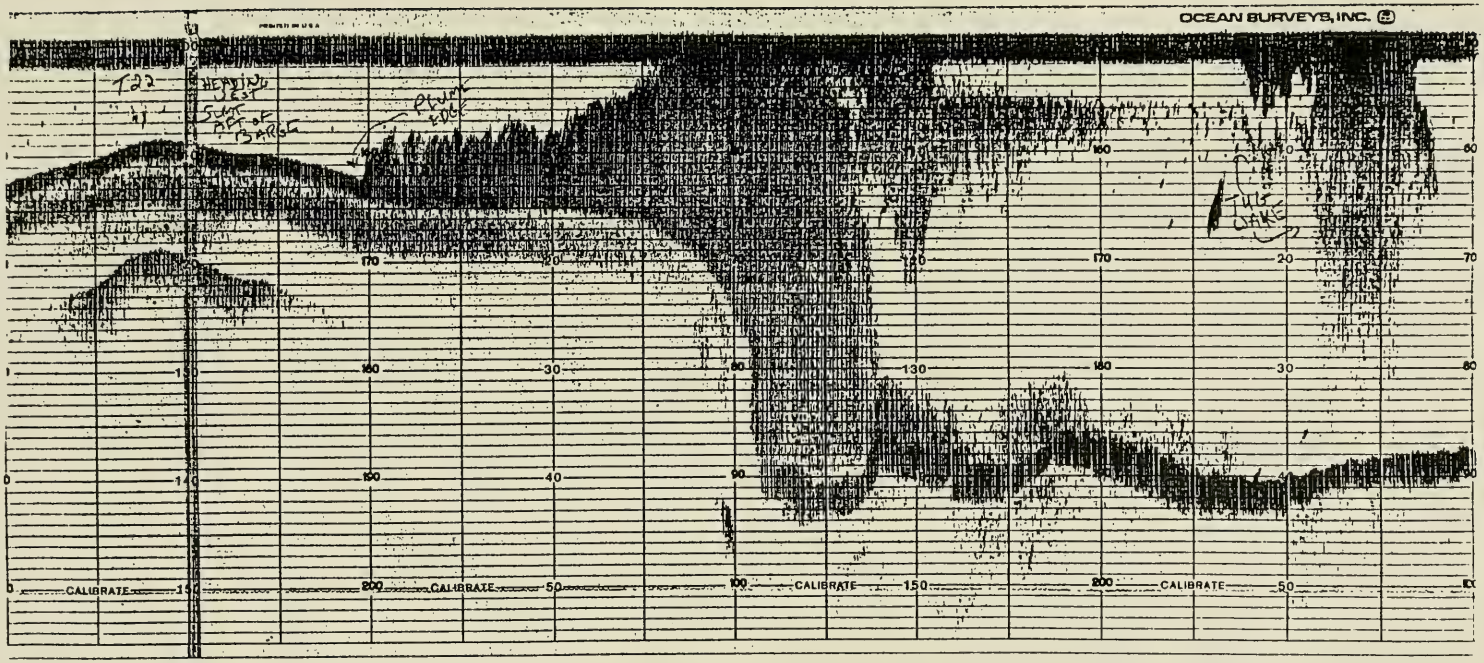
End segment of Transect #20 acoustic survey of 3 November 1993; profile runs east to west



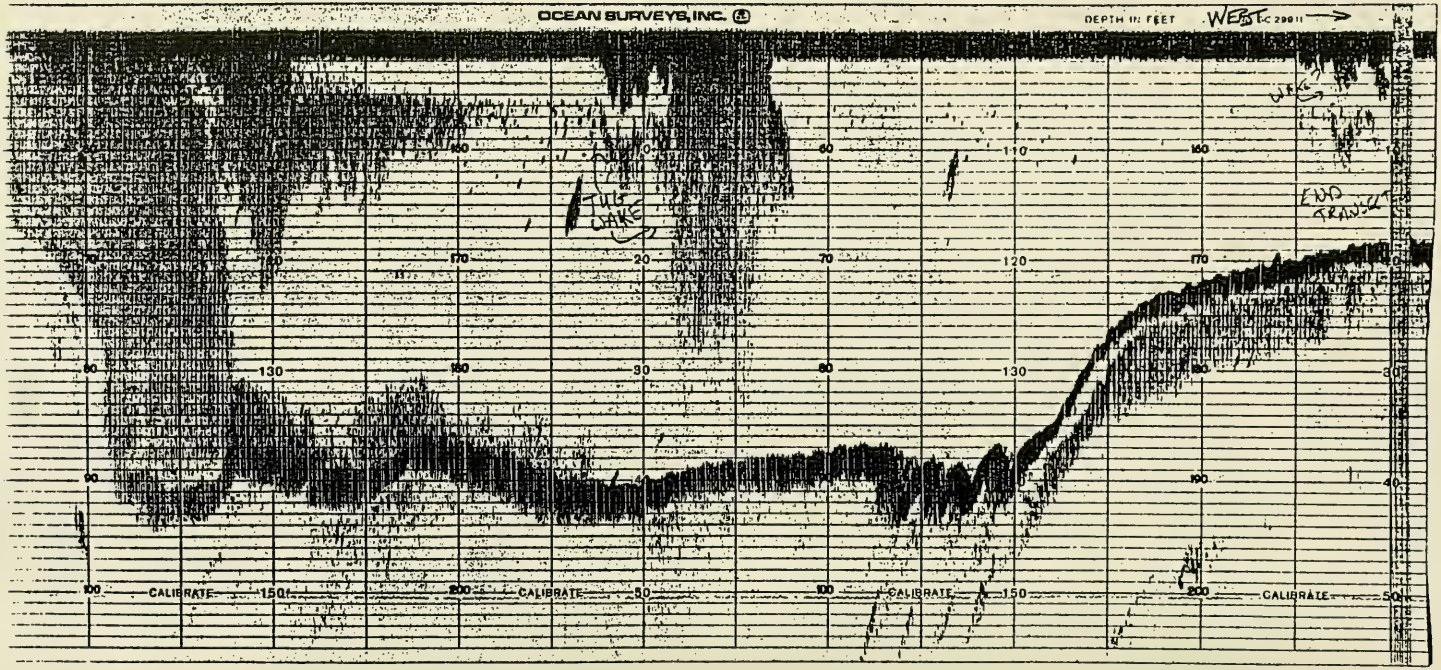
Beginning segment of Transect #21 acoustic survey of 3 November 1993; profile runs west to east



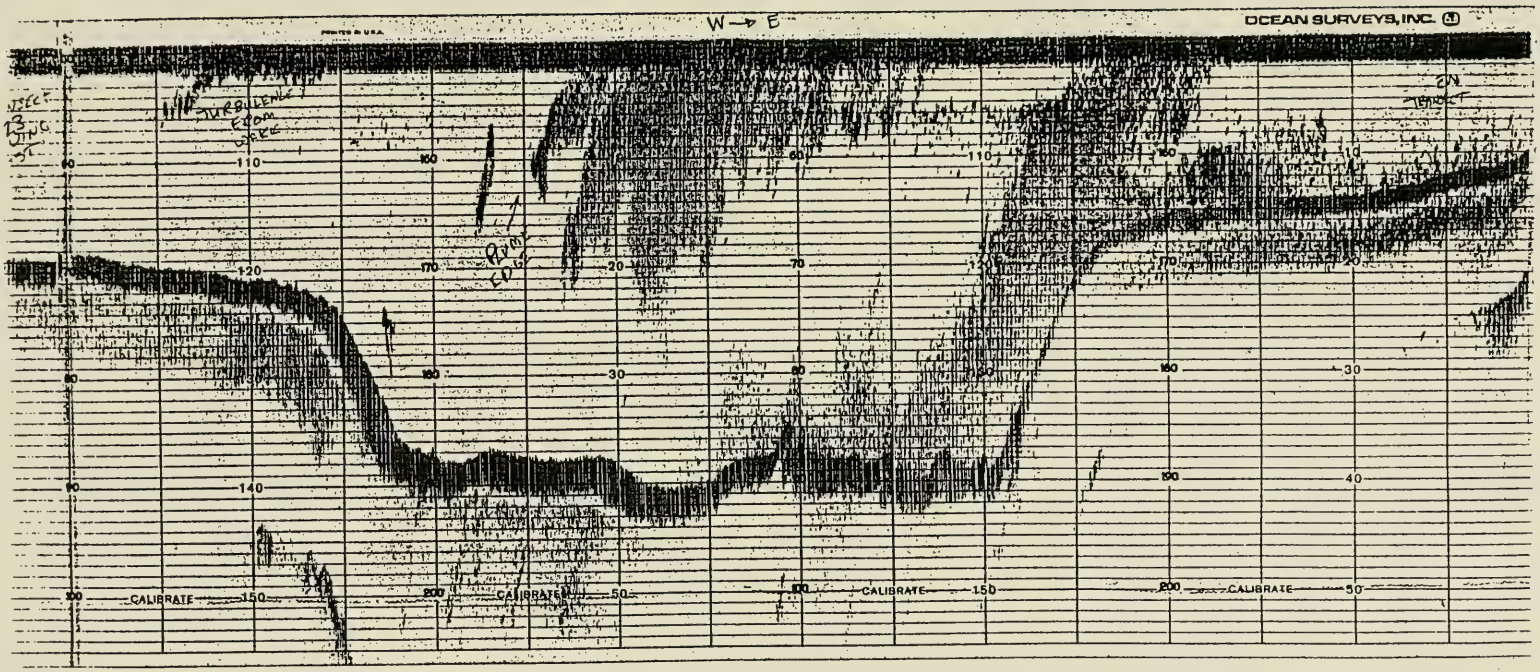
End segment of Transect #21 acoustic survey of 3 November 1993; profile runs west to east



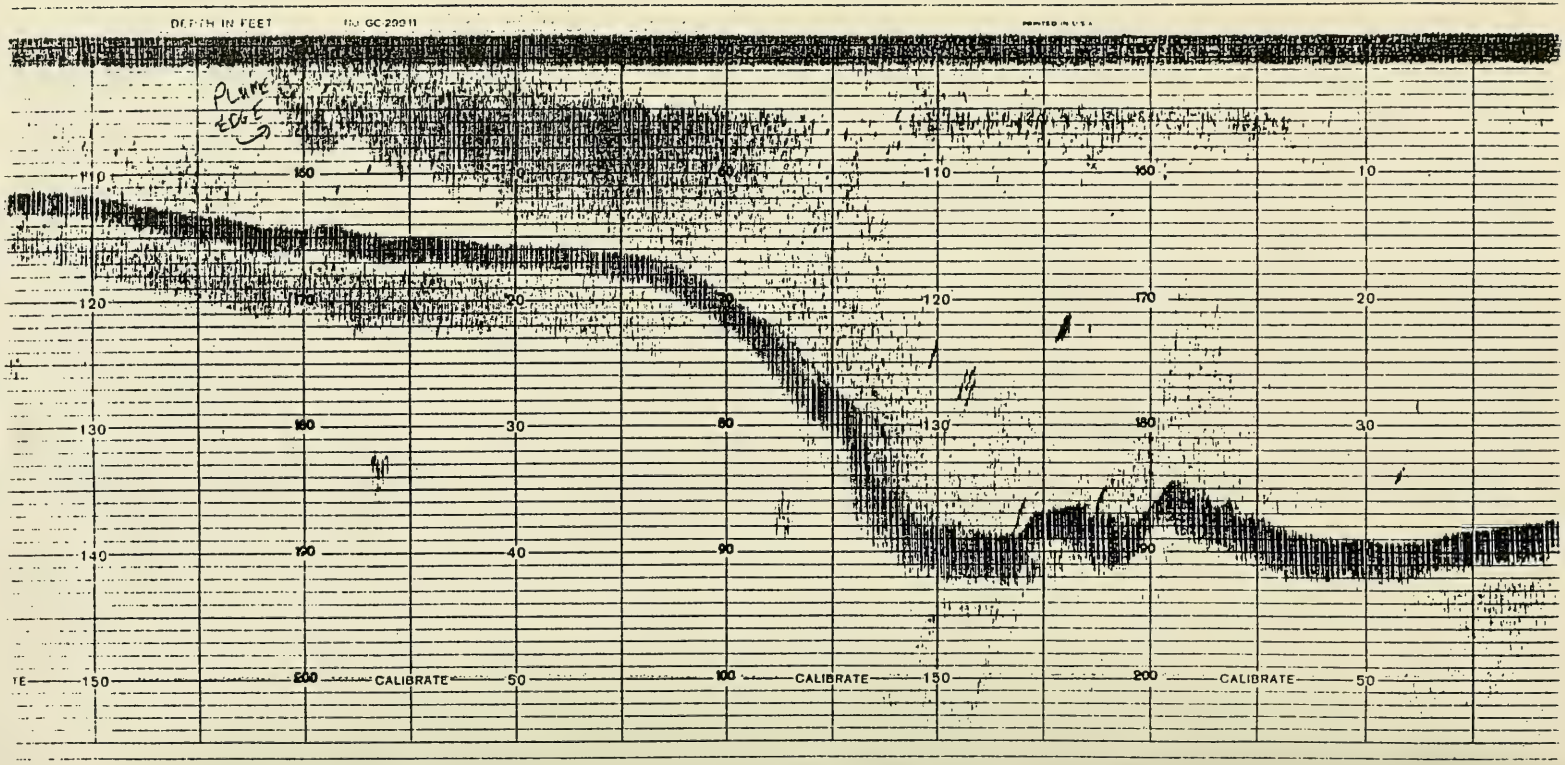
Beginning segment of Transect #22 acoustic survey of 11 November 1993; profile runs east to west



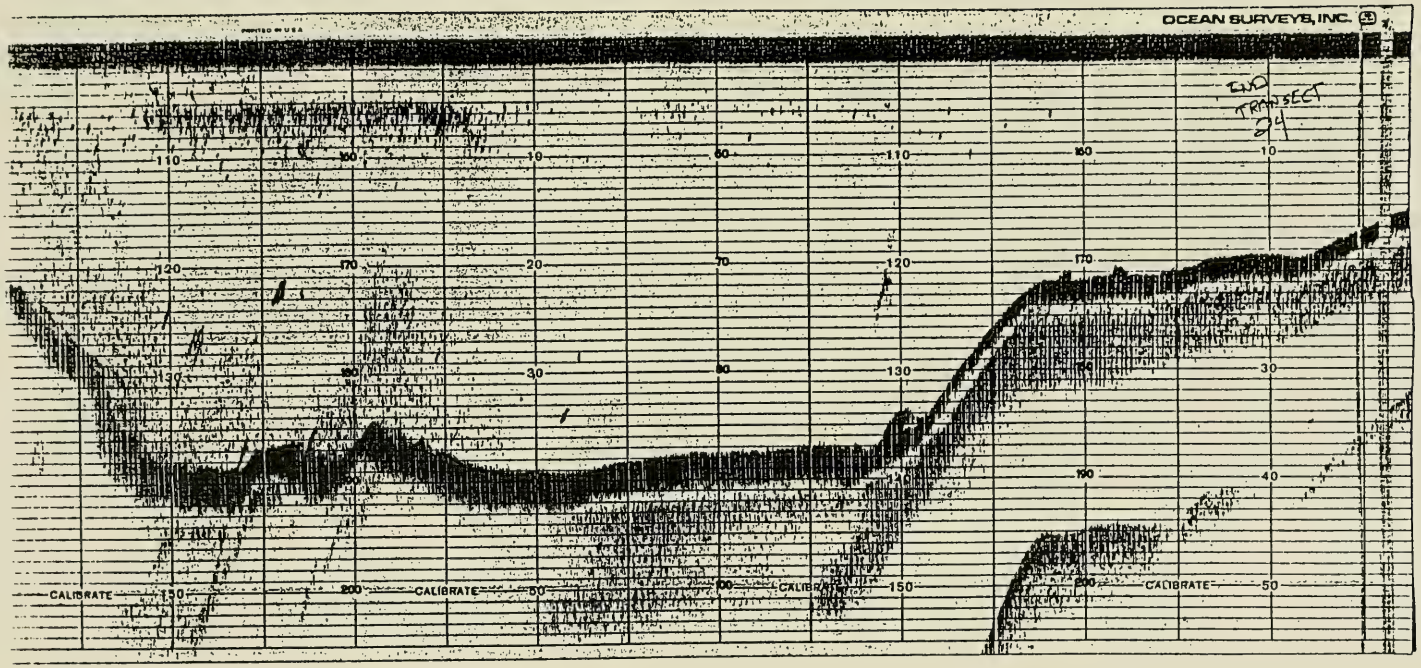
End segment of Transect #22 acoustic survey of 11 November 1993; profile runs east to west



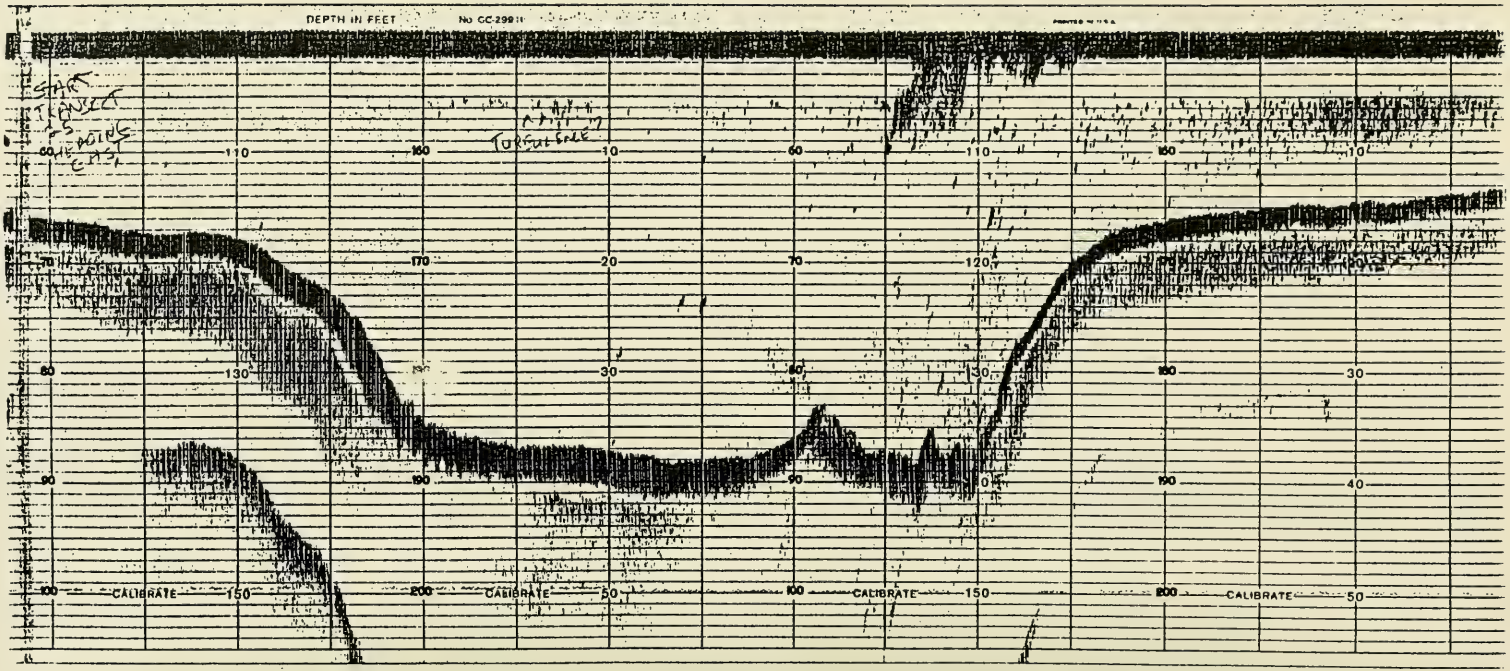
Transect #23 acoustic survey of 11 November 1993; profile runs west to east



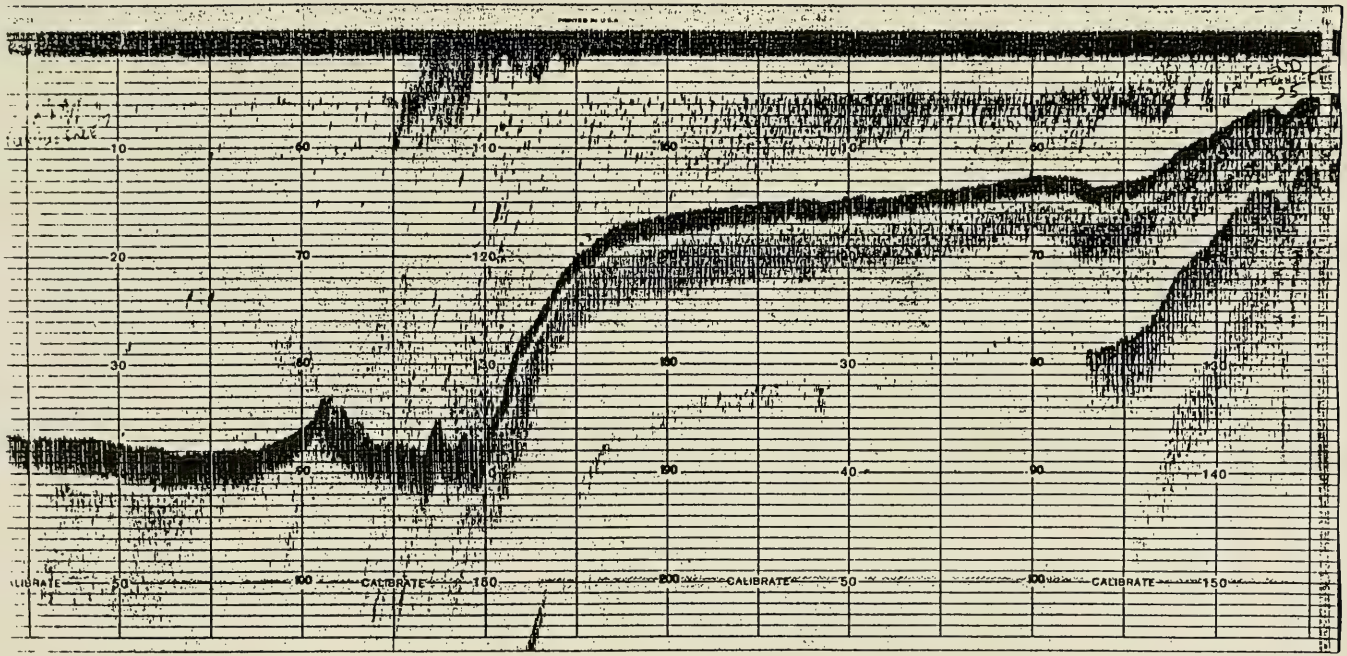
Beginning segment of Transect #24 acoustic survey of 11 November 1993; profile runs east to west



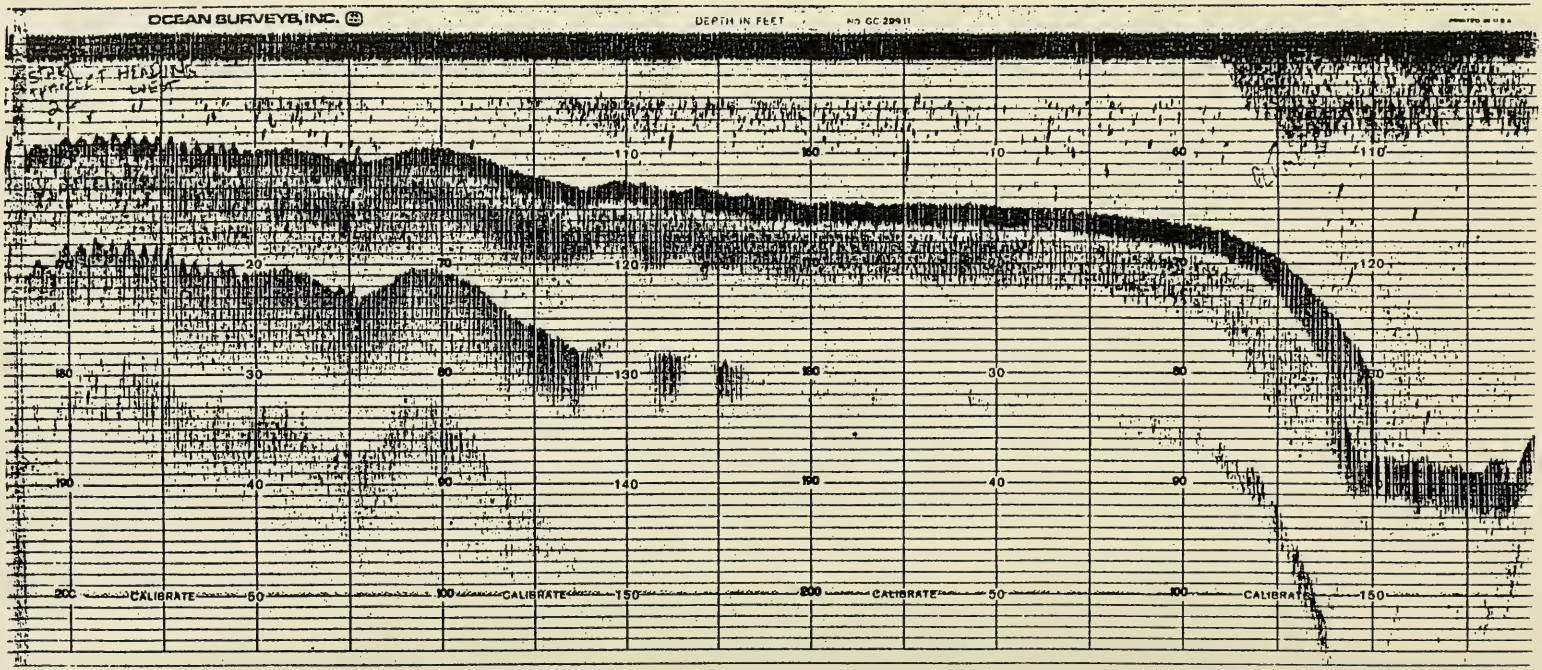
End segment of Transect #24 acoustic survey of 11 November 1993; profile runs east to west



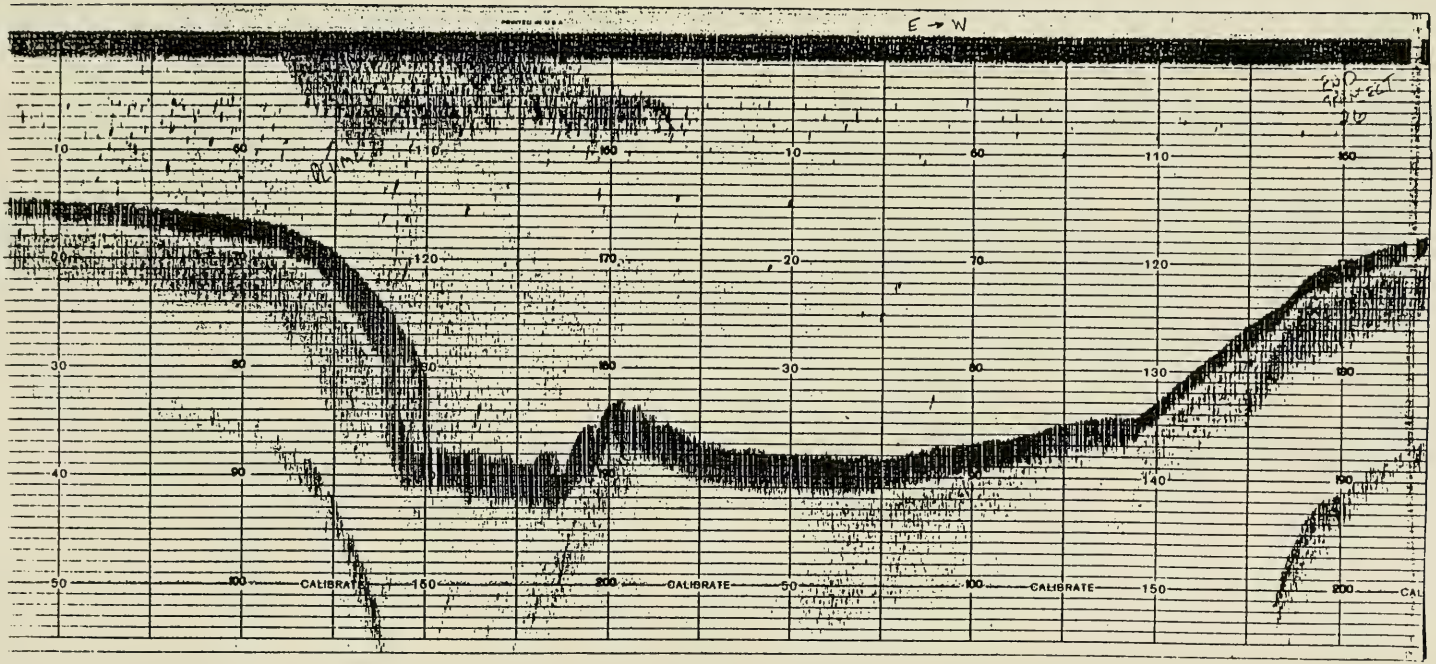
Beginning segment of Transect #25 acoustic survey of 11 November 1993; profile runs west to east



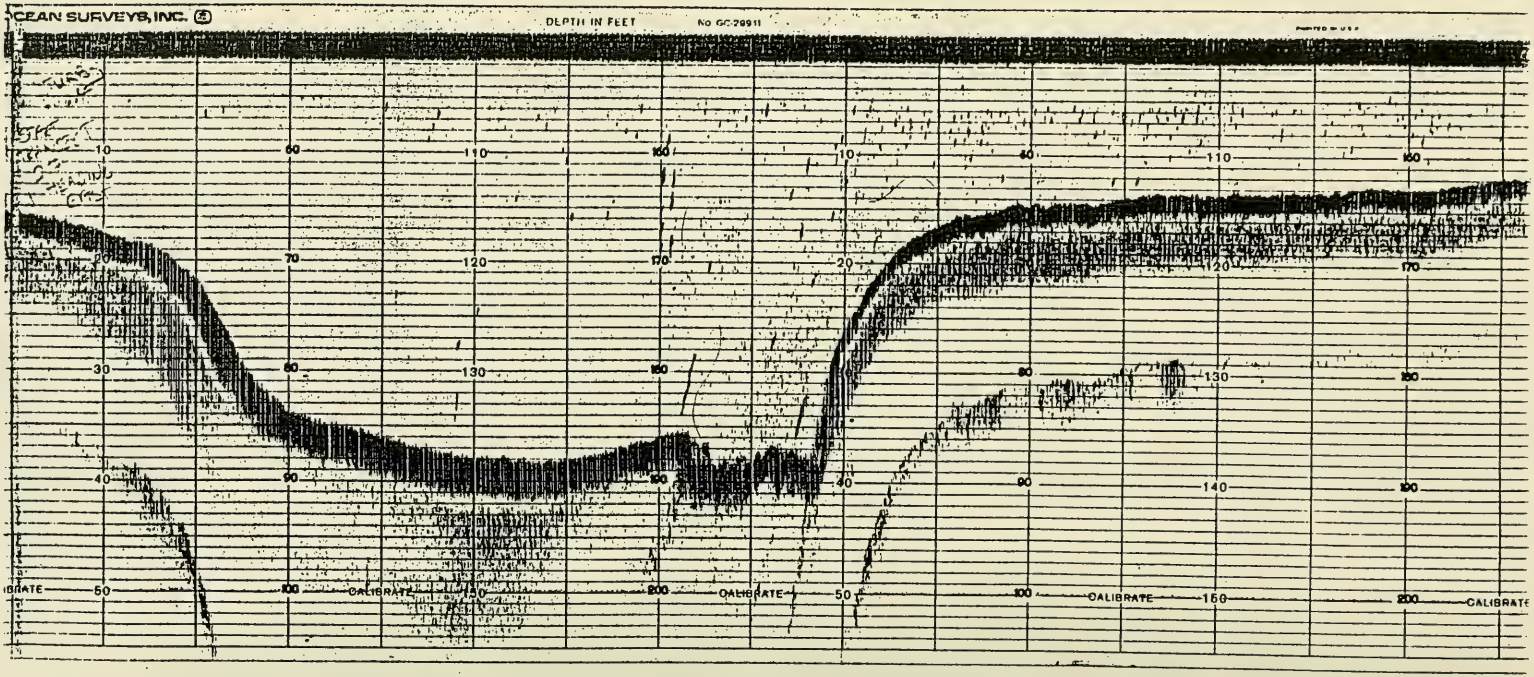
End segment of Transect #25 acoustic survey of 11 November 1993; profile runs west to east



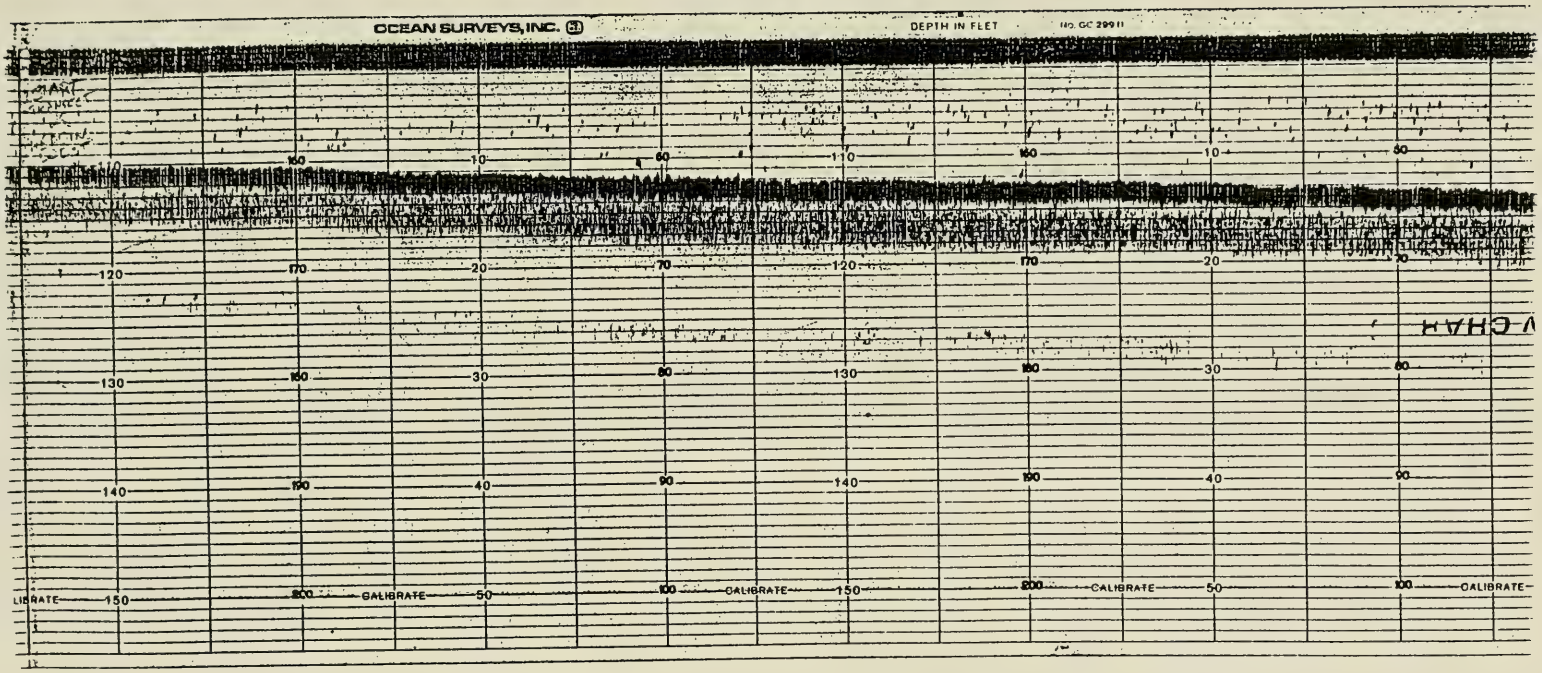
Beginning segment of Transect #26 acoustic survey of 11 November 1993; profile runs east to west



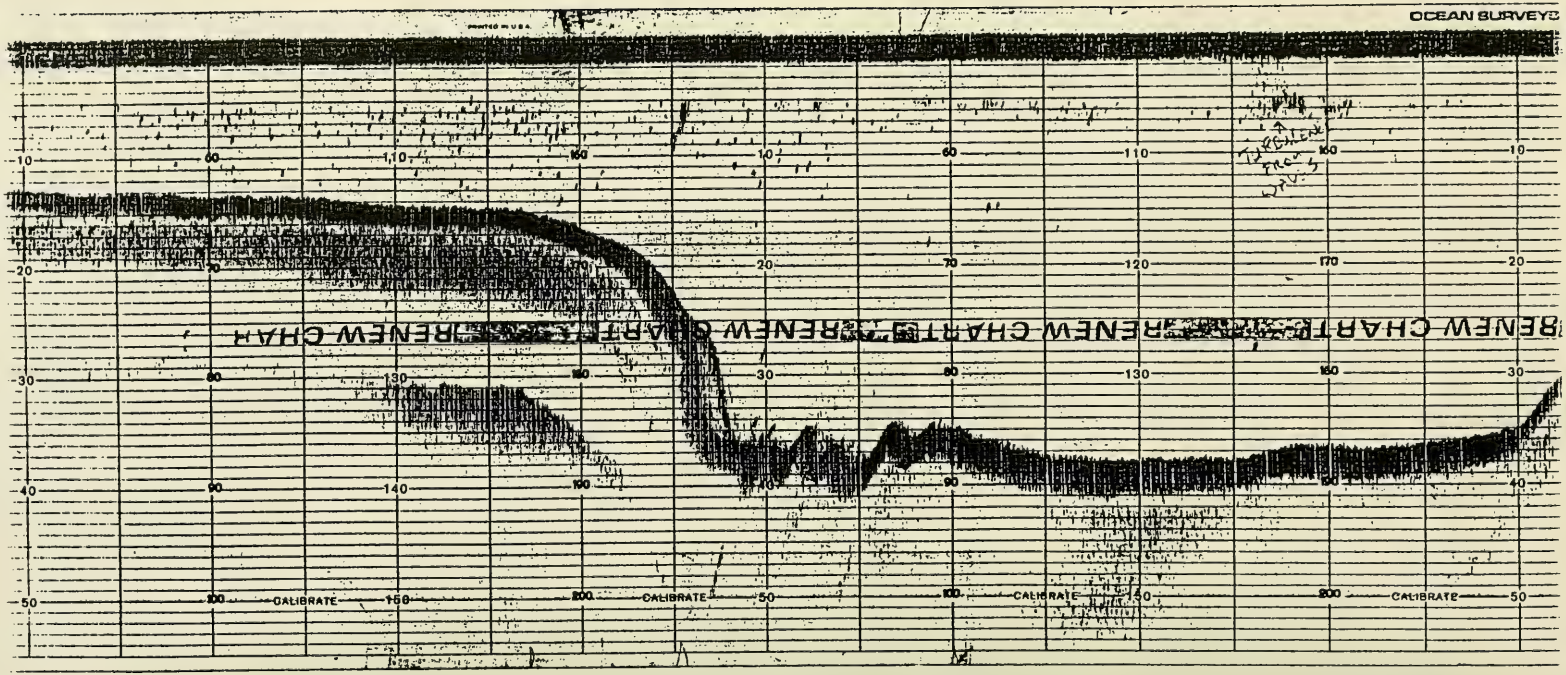
End segment of Transect #26 acoustic survey of 11 November 1993; profile runs east to west



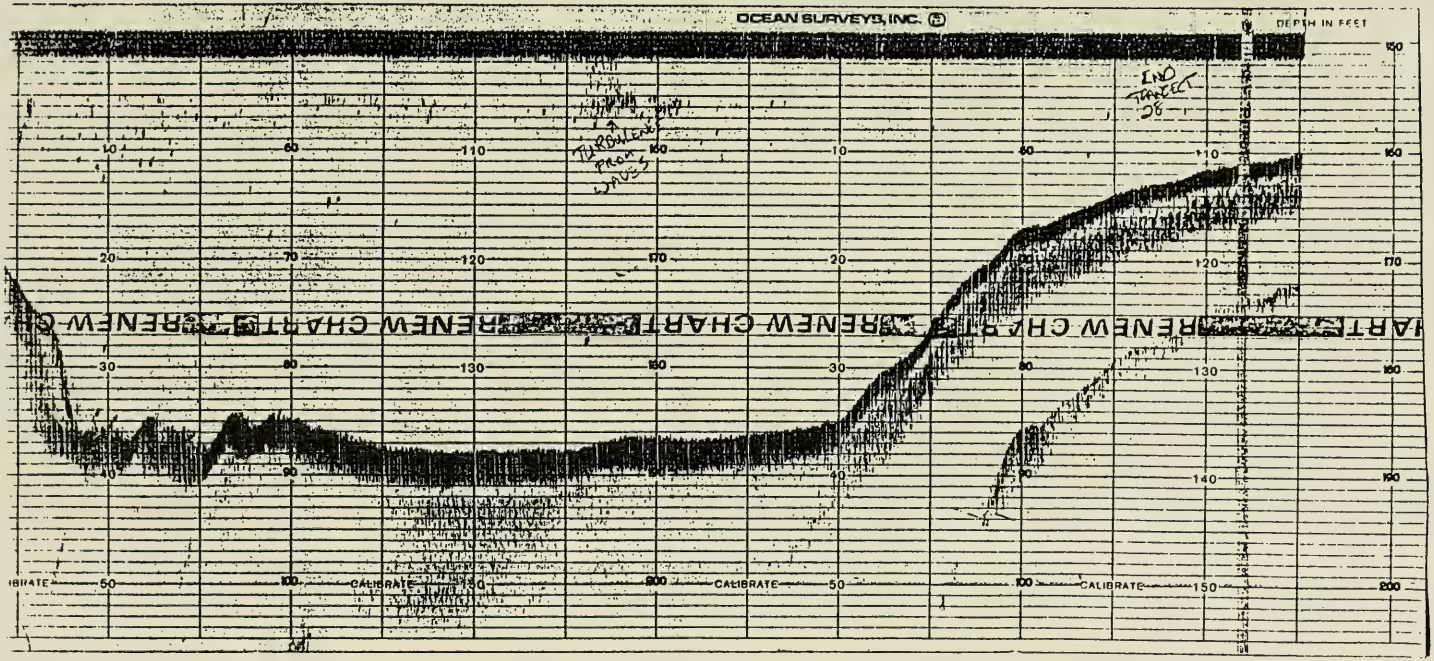
Transect #27 acoustic survey of 11 November 1993; profile runs west to east



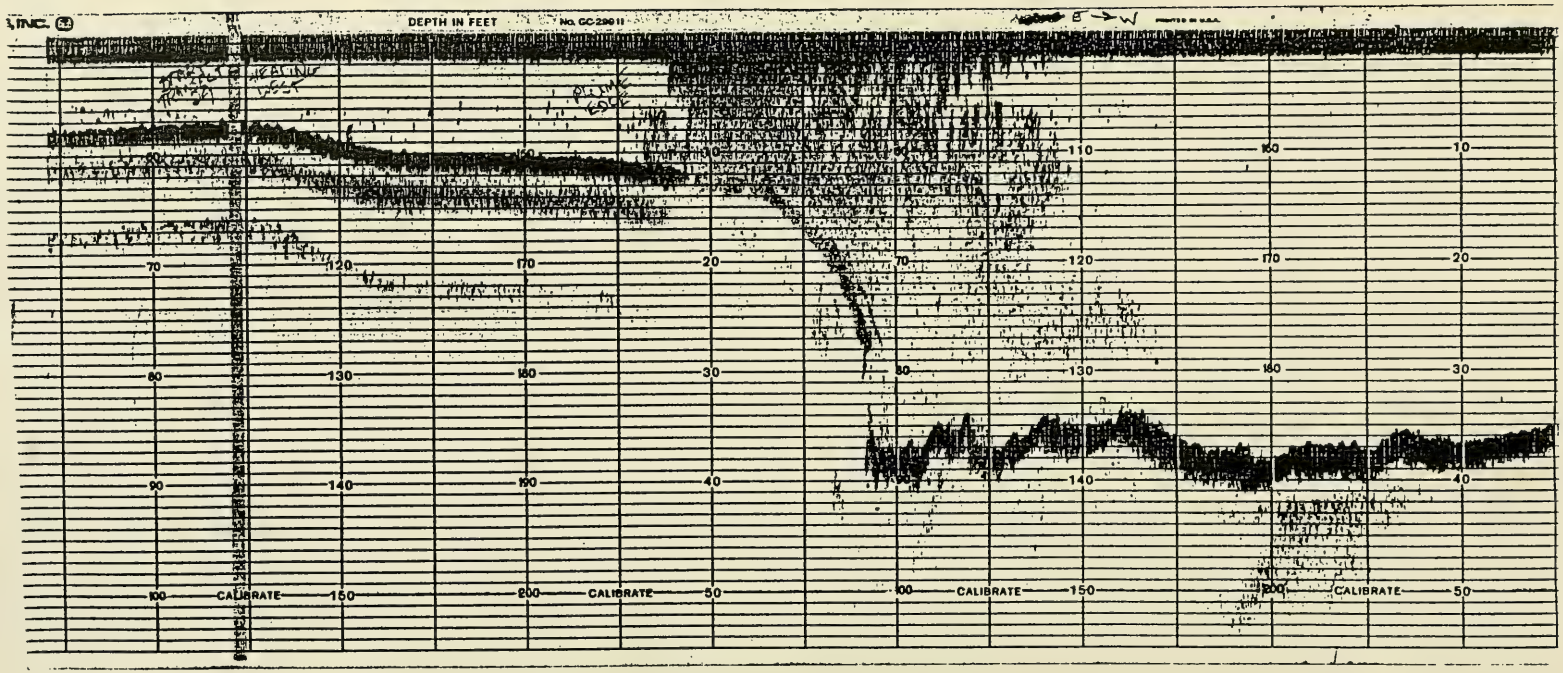
Beginning segment of Transect #28 acoustic survey of 11 November 1993; profile runs east to west



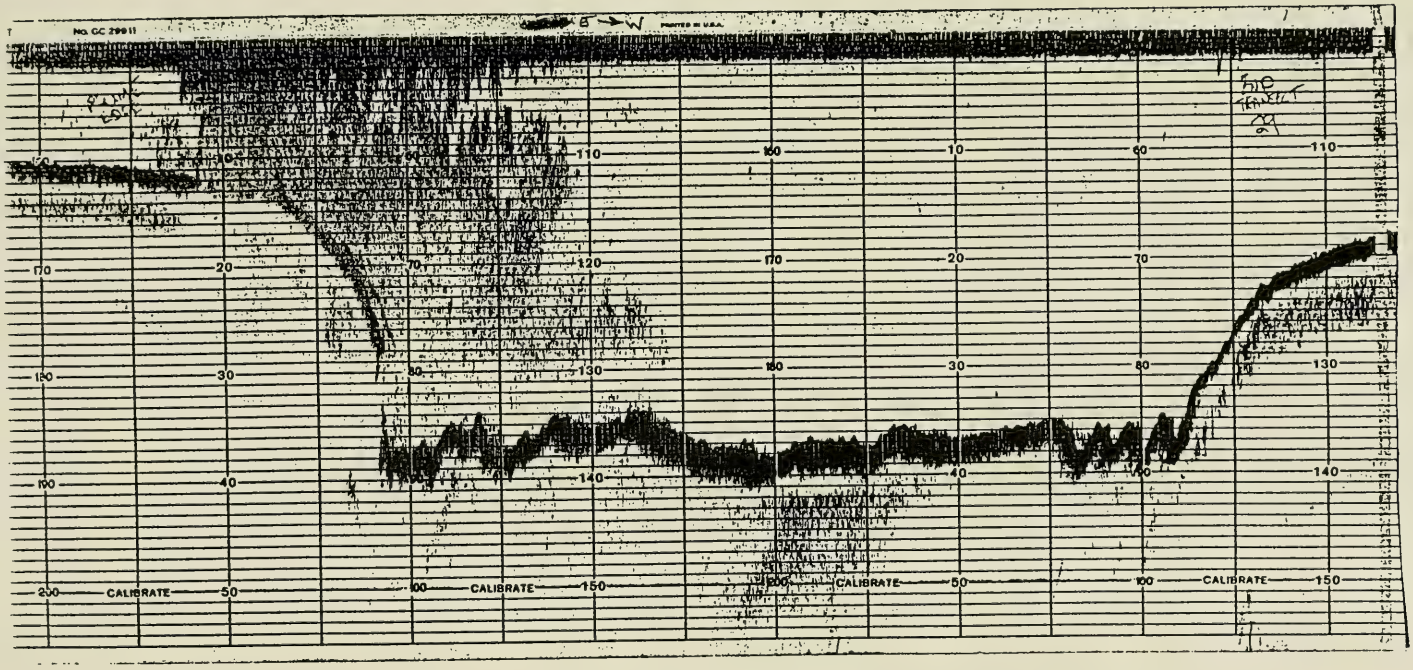
Middle segment of Transect #28 acoustic survey of 11 November 1993; profile runs east to west



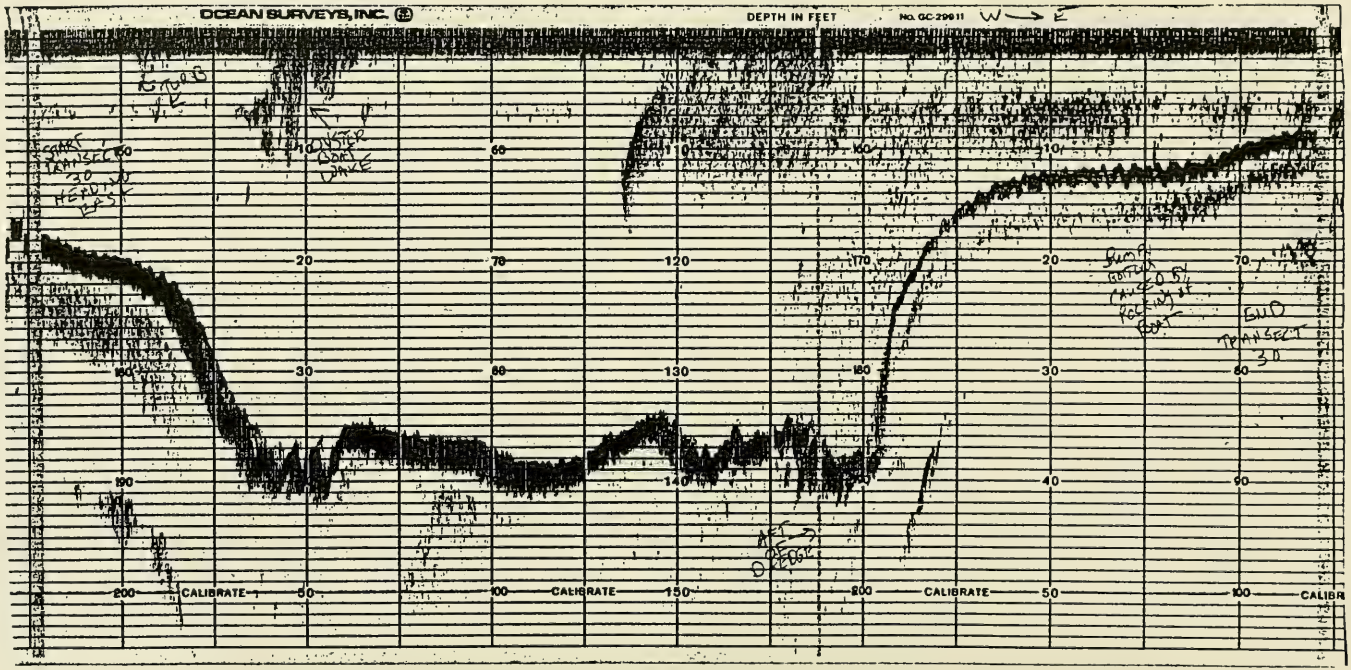
End segment of Transect #28 acoustic survey of 11 November 1993; profile runs east to west



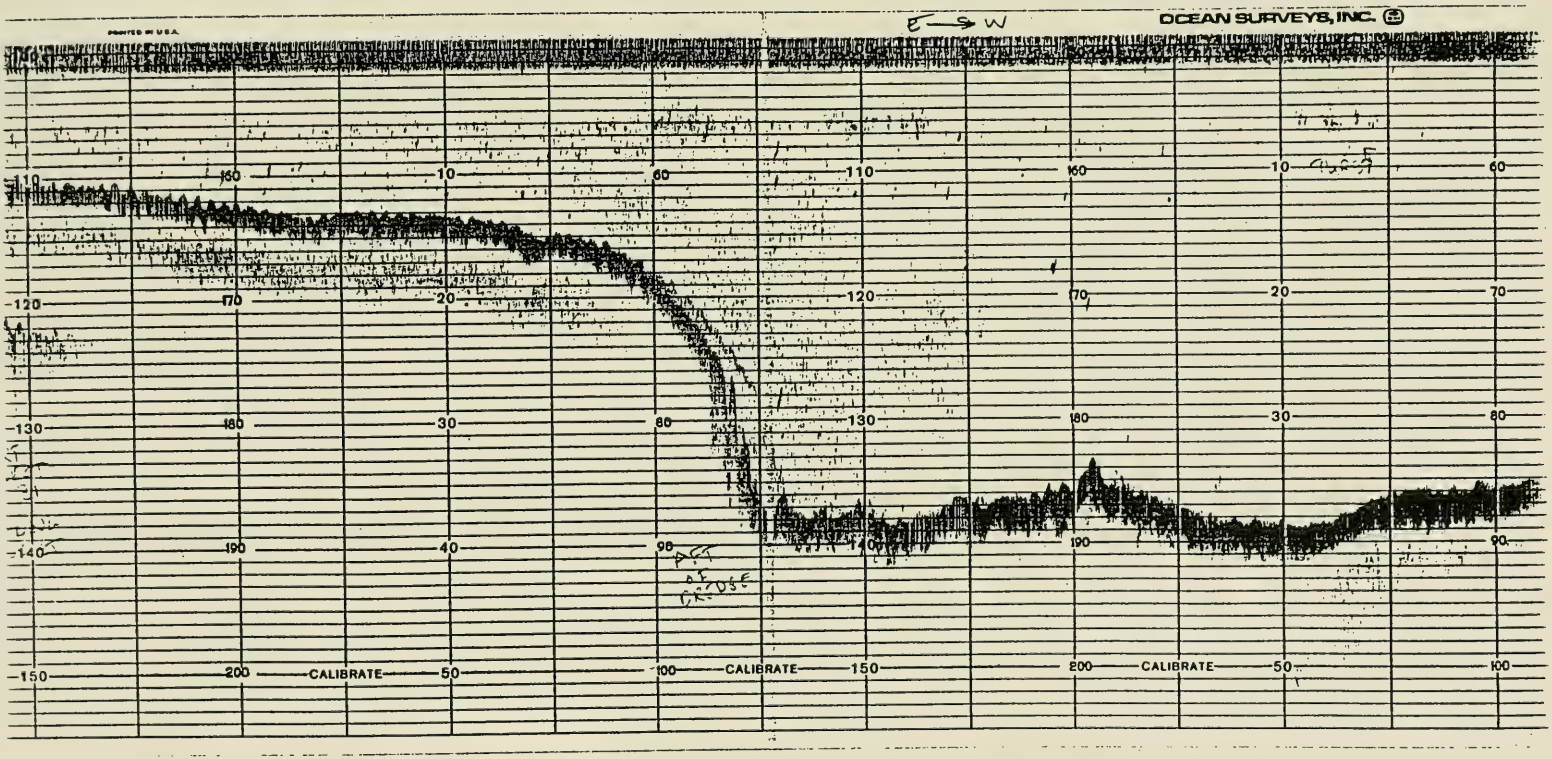
Beginning segment of Transect #29 acoustic survey of 11 November 1993; profile runs east to west



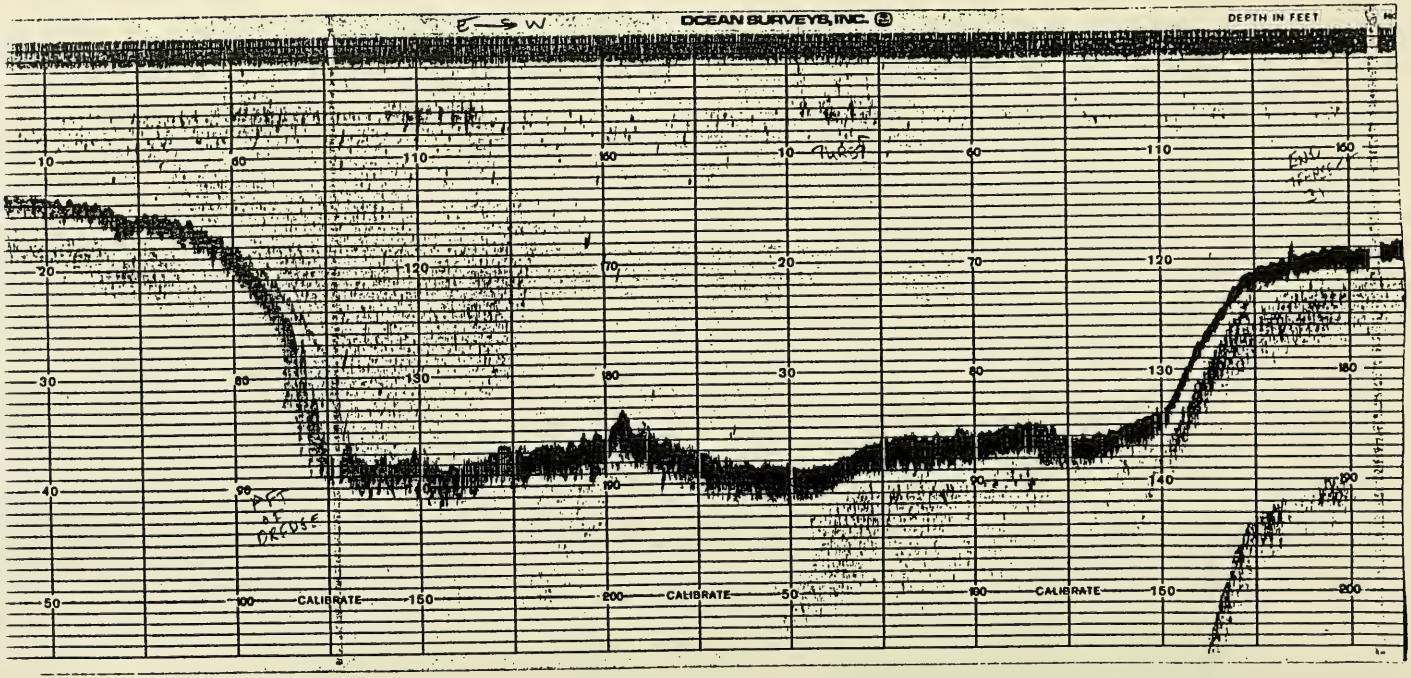
End segment of Transect #29 acoustic survey of 11 November 1993; profile runs east to west



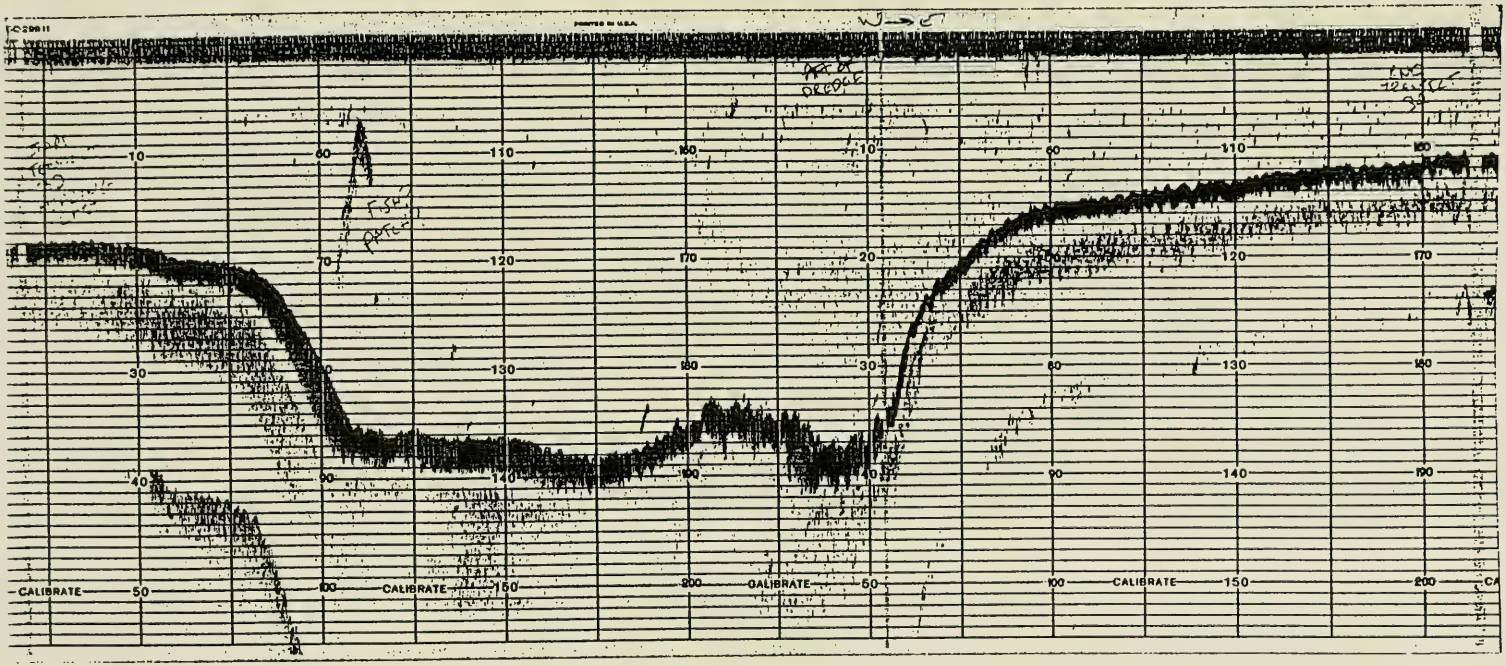
Transect #30 acoustic survey of 11 November 1993; profile runs west to east



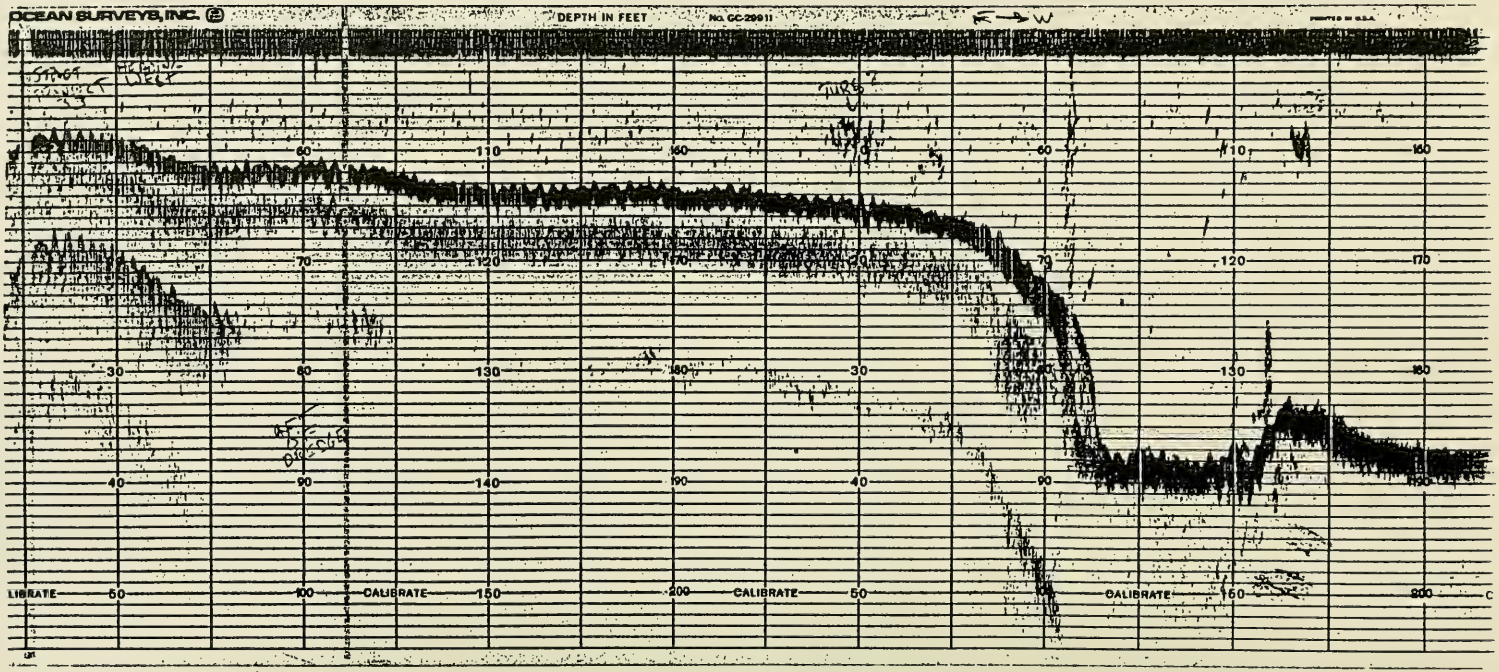
Beginning segment of Transect #31 acoustic survey of 11 November 1993; profile runs east to west



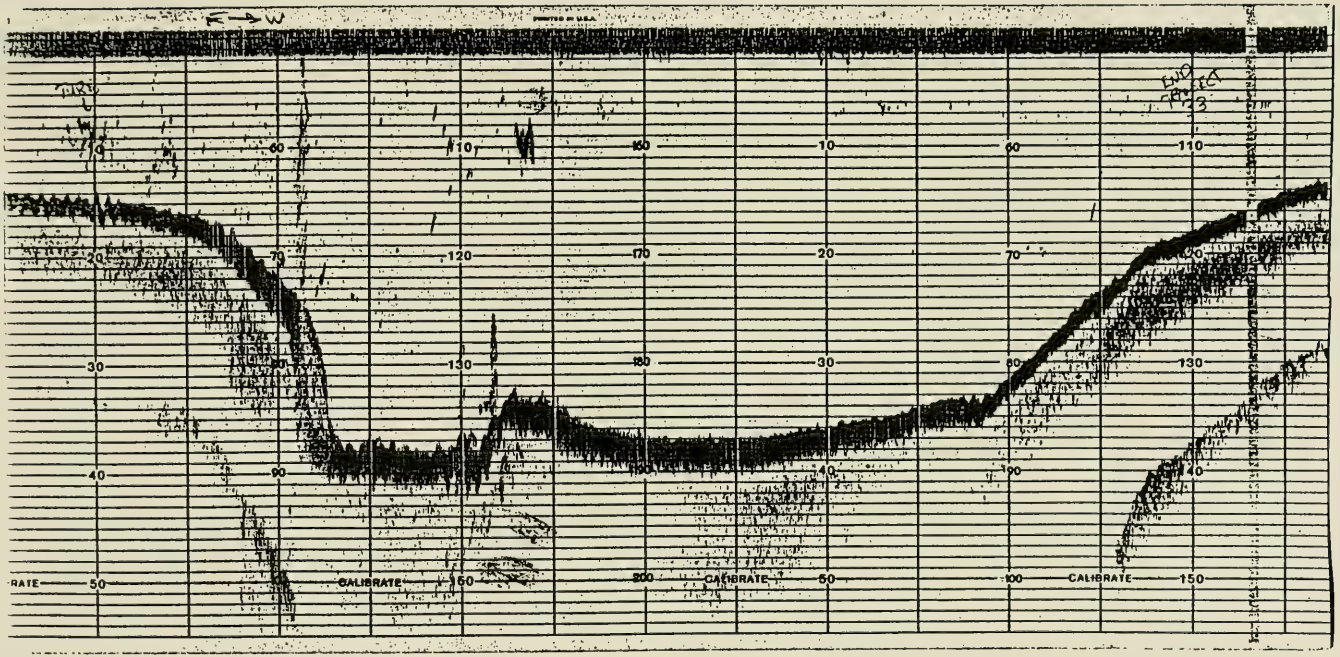
End segment of Transect #31 acoustic survey of 11 November 1993; profile runs east to west



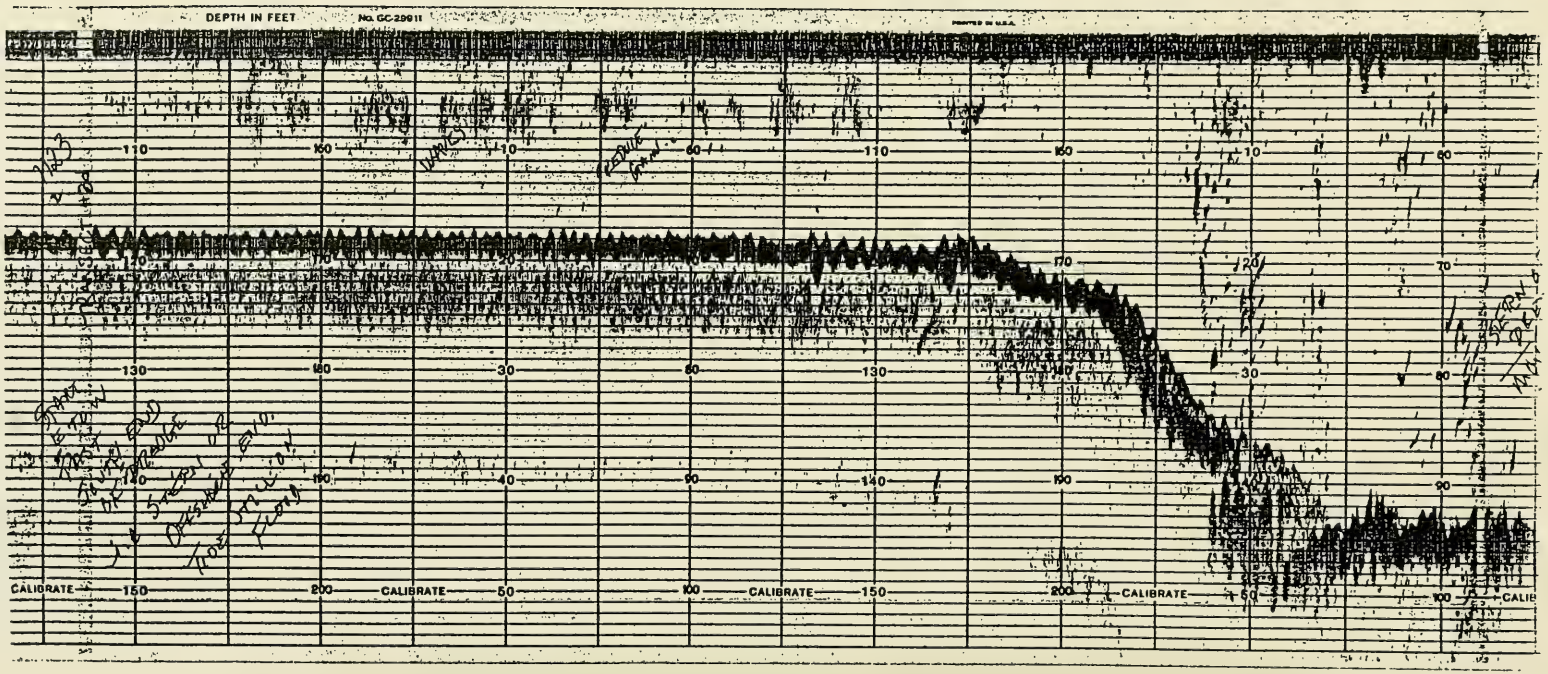
Transect #32 acoustic survey of 11 November 1993; profile runs west to east



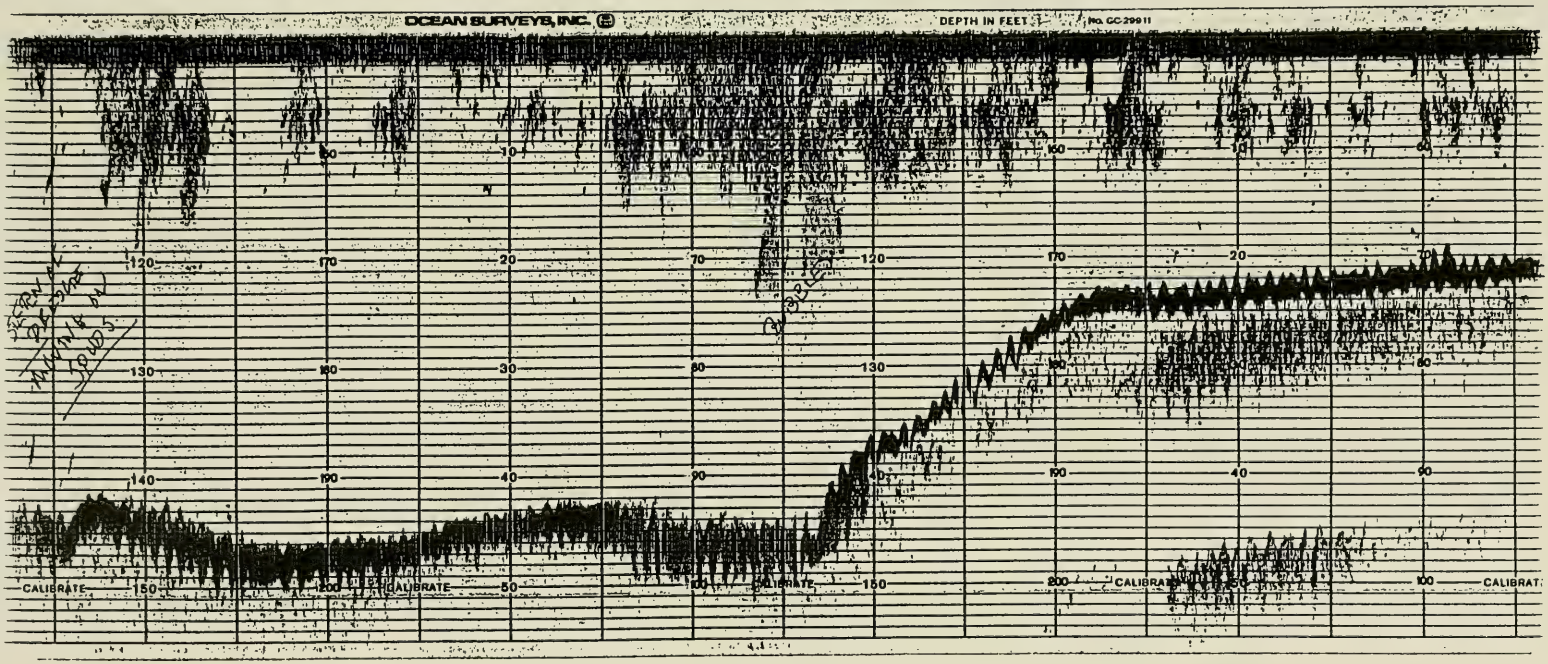
Beginning segment of Transect #33 acoustic survey of 11 November 1993; profile runs east to west



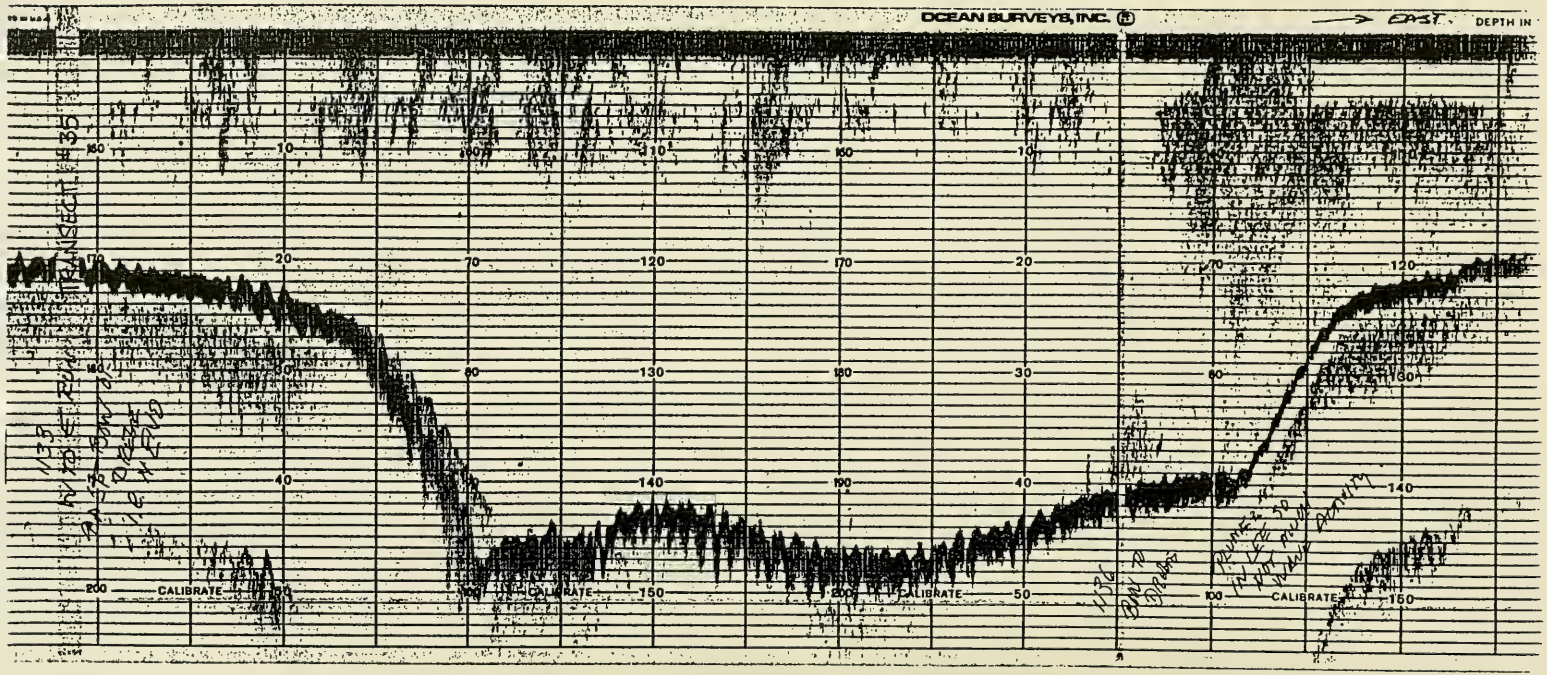
End segment of Transect #33 acoustic survey of 11 November 1993; profile runs east to west



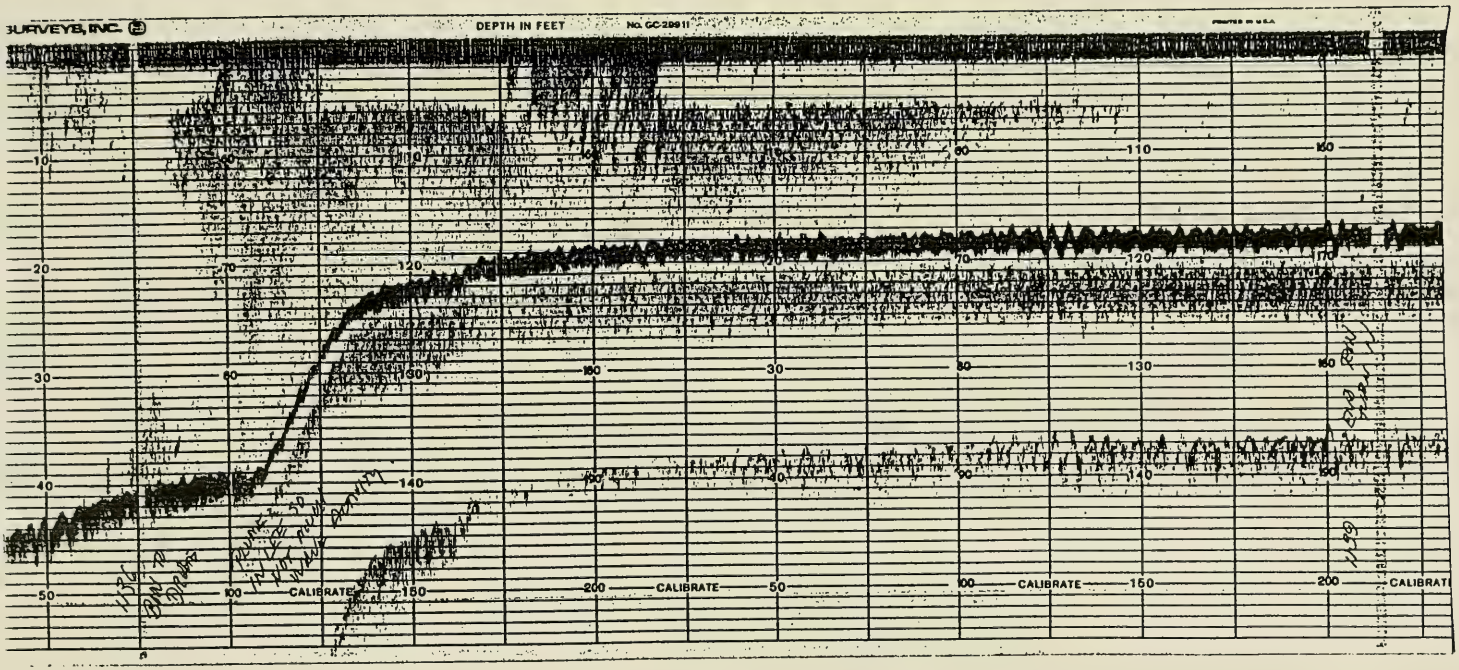
Beginning segment of Transect #34 acoustic survey of 15 November 1993; profile runs east to west



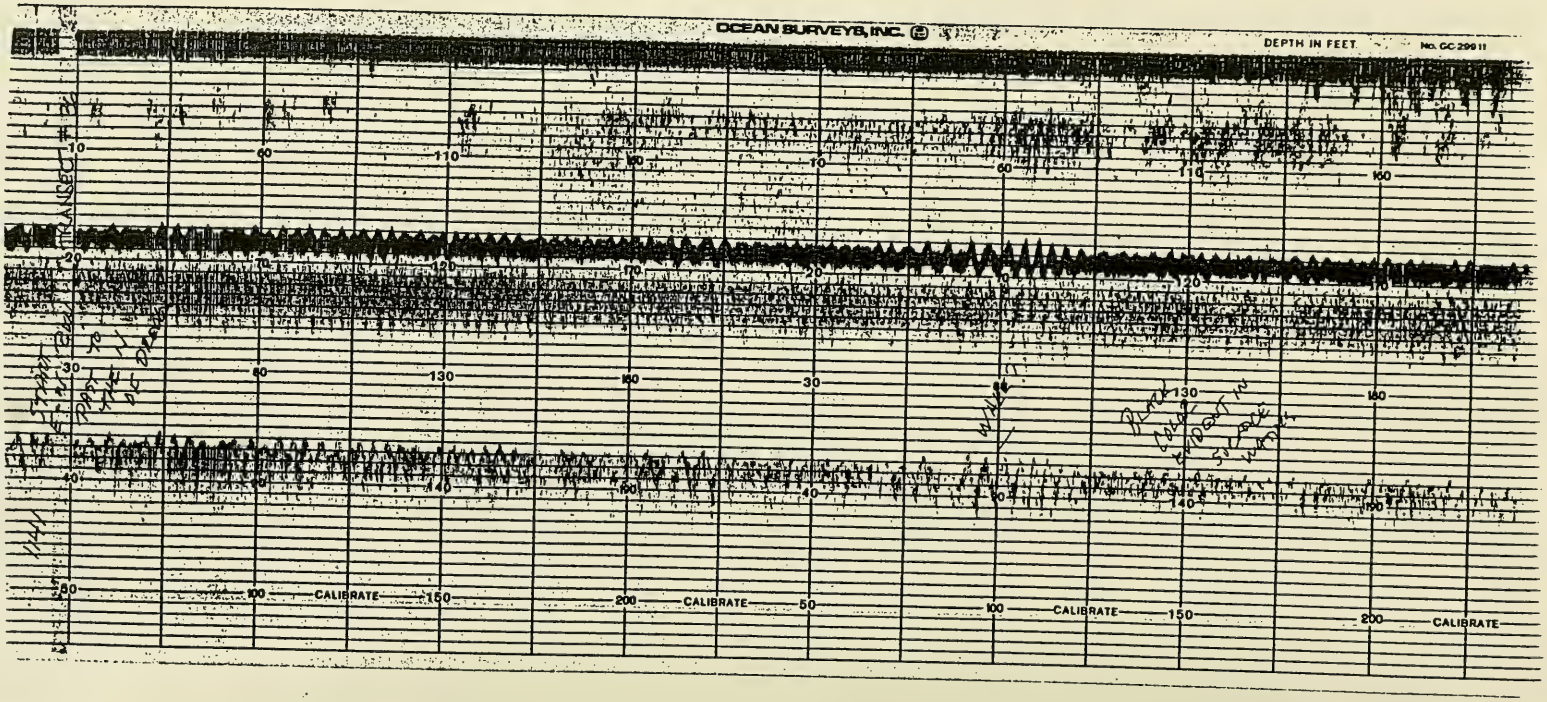
End segment of Transect #34 acoustic survey of 15 November 1993; profile runs east to west



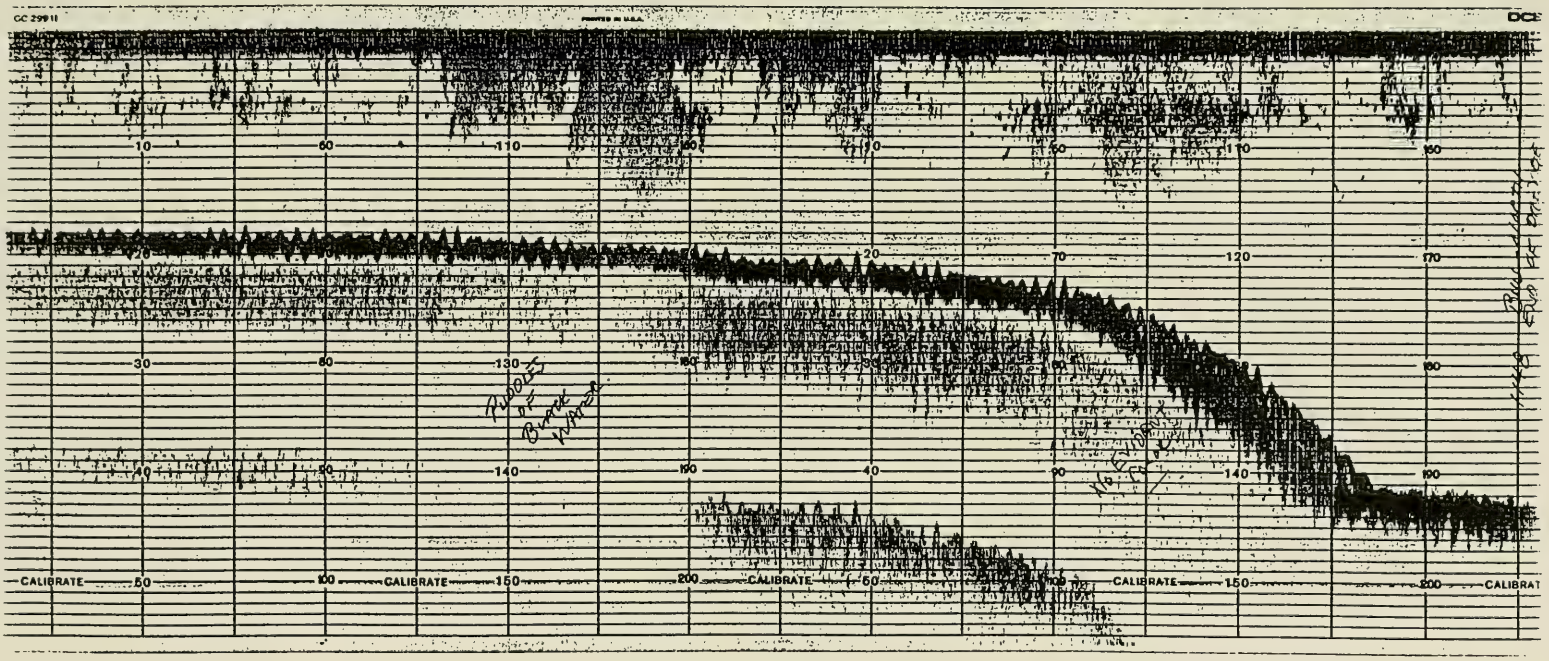
Beginning segment of Transect #35 acoustic survey of 15 November 1993; profile runs west to east



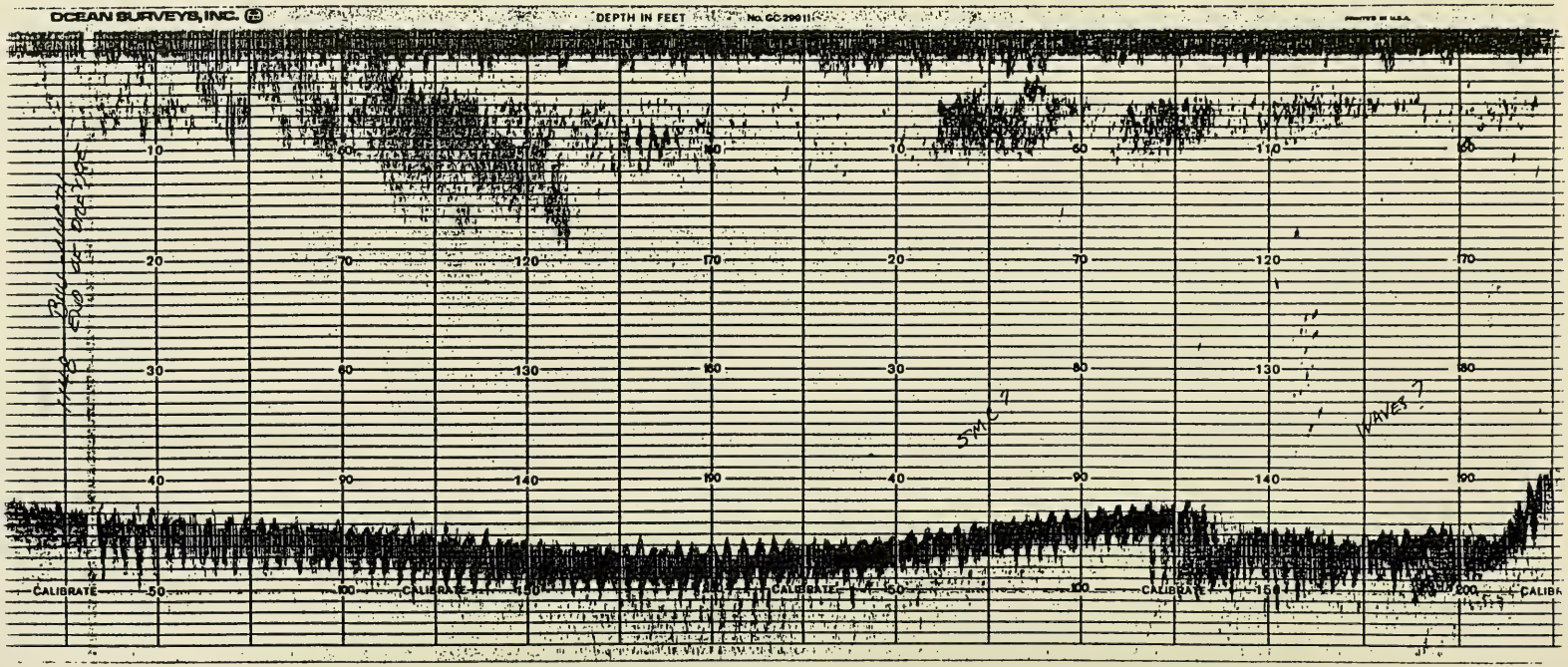
End segment of Transect #35 acoustic survey of 15 November 1993; profile runs west to east



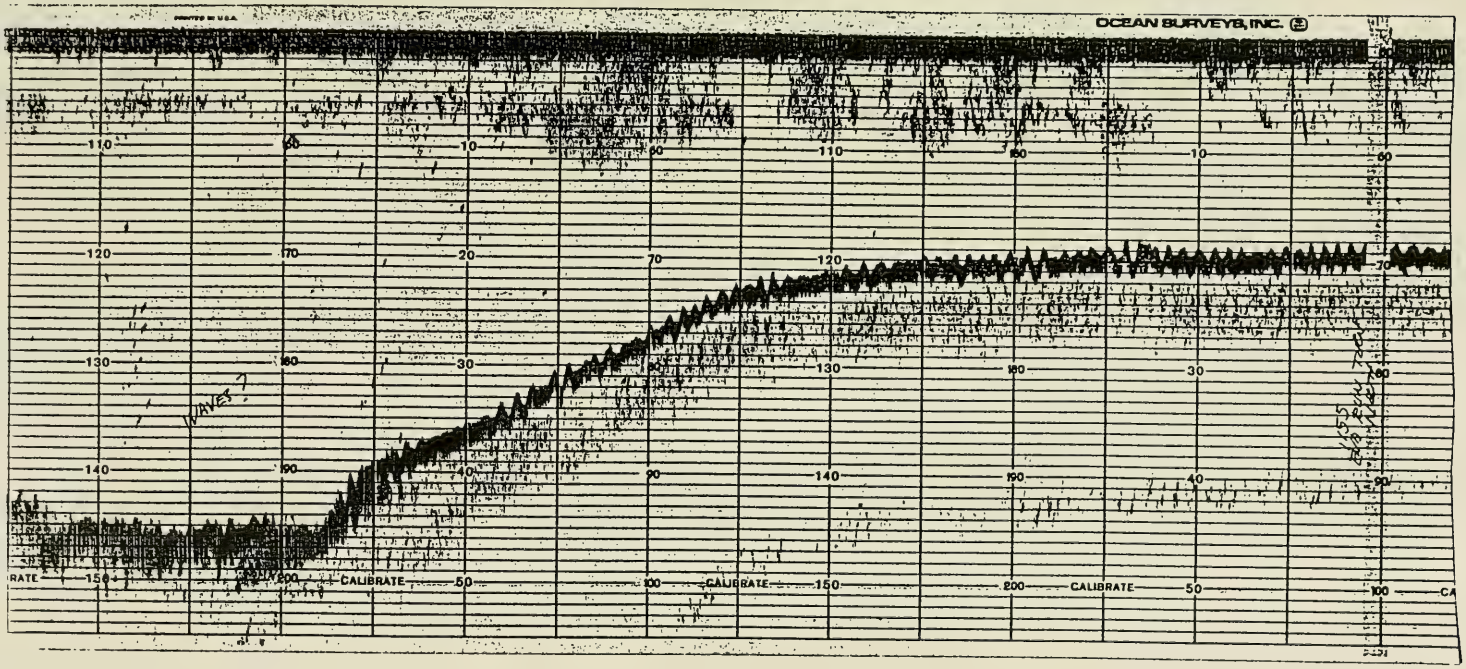
First of 4 segments for Transect #36 acoustic survey of 15 November 1993; profile runs east to west



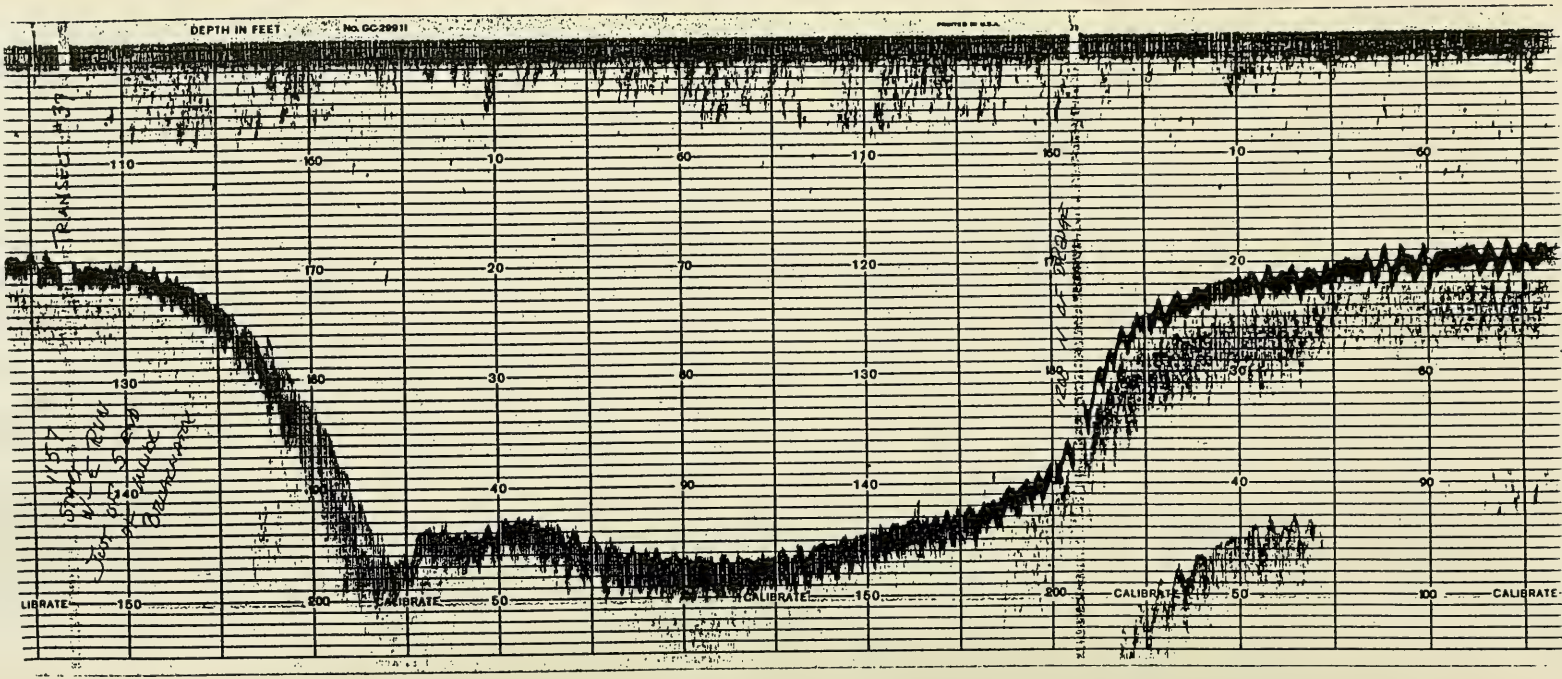
Second of 4 segments for Transect #36 acoustic survey of 15 November 1993; profile runs east to west



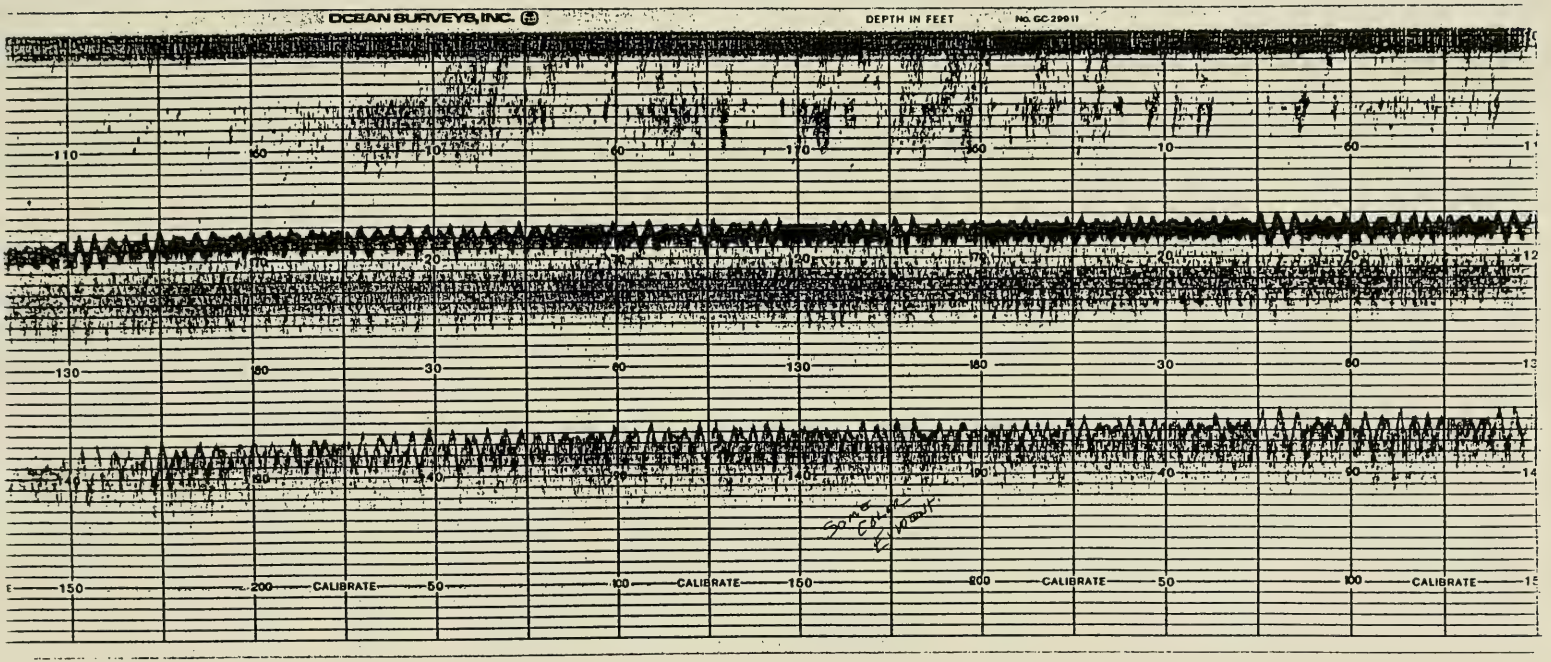
Third of 4 segments for Transect #36 acoustic survey of 15 November 1993; profile runs east to west



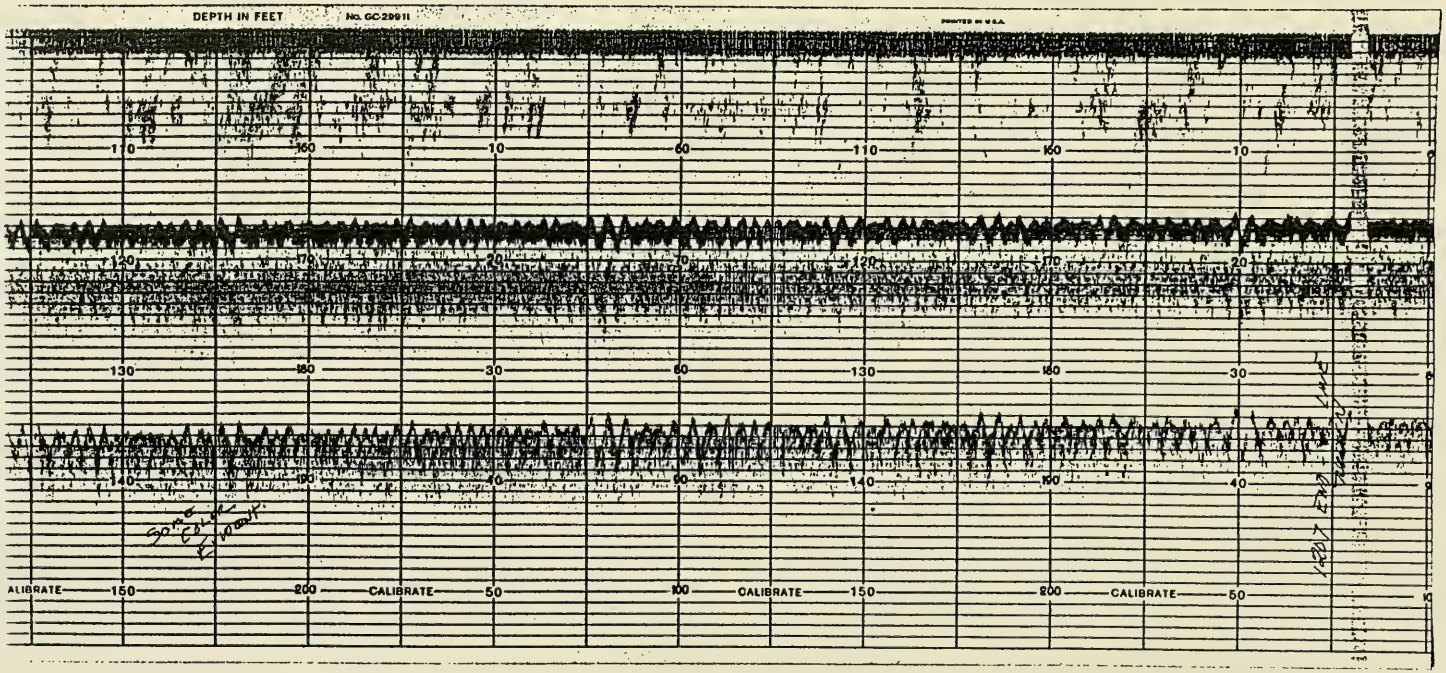
Fourth of 4 segments for Transect #36 acoustic survey of 15 November 1993; profile runs east to west



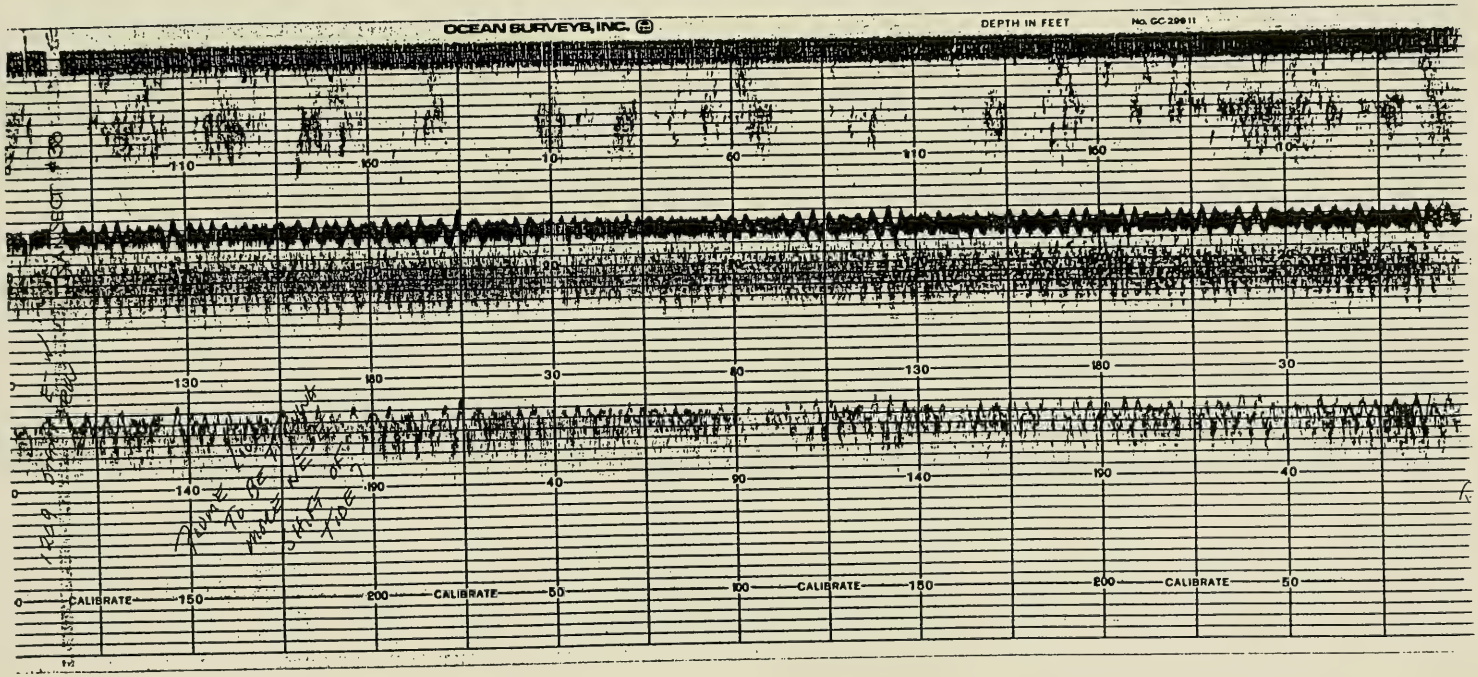
Beginning segment of Transect #37 acoustic survey of 15 November 1993; profile runs west to east



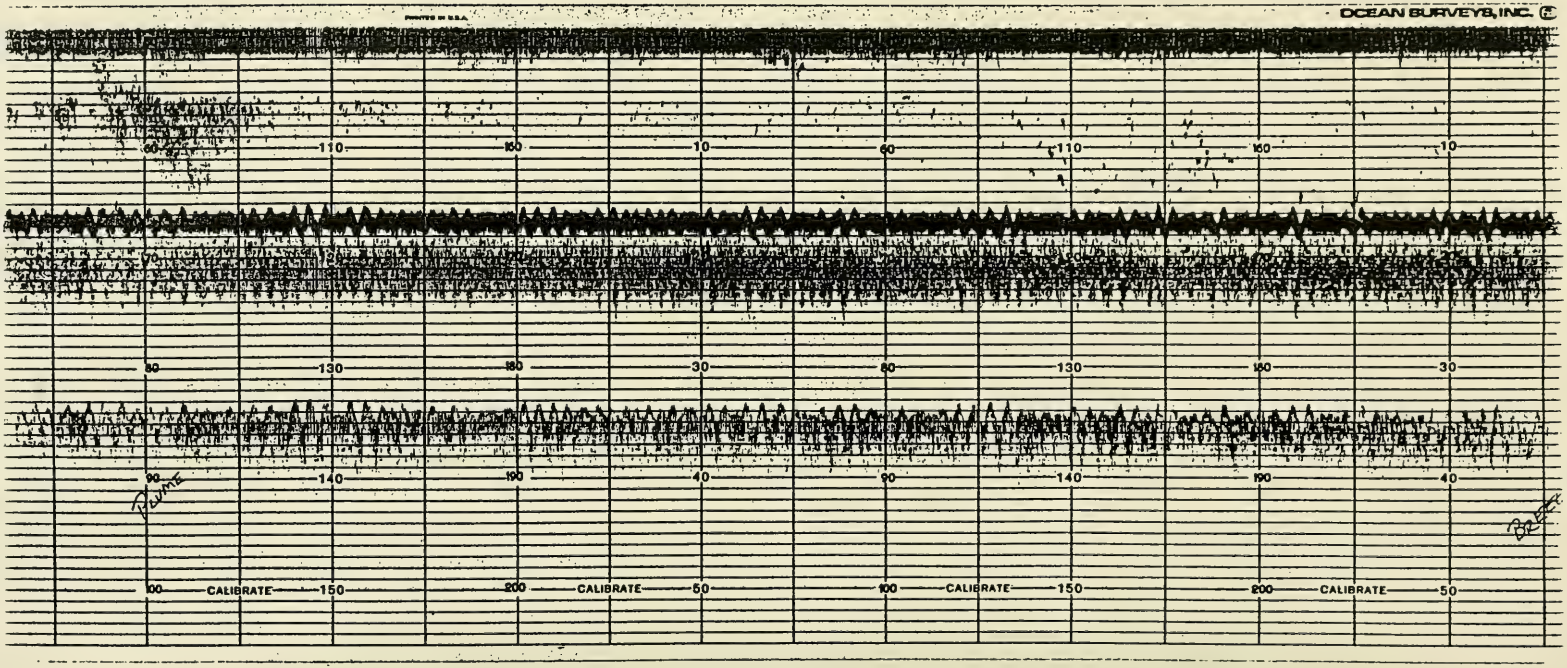
Middle segment of Transect #37 acoustic survey of 15 November 1993; profile runs west to east



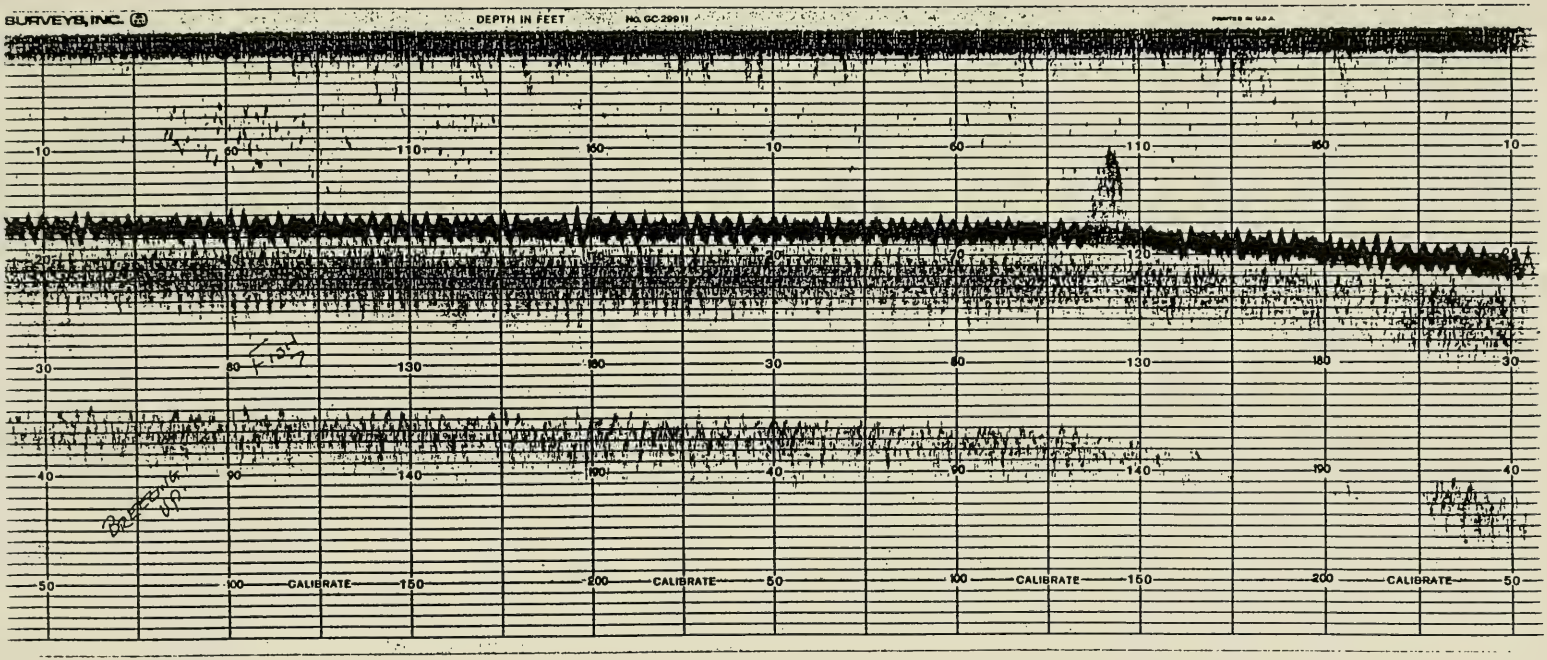
End segment of Transect #37 acoustic survey of 15 November 1993; profile runs west to east



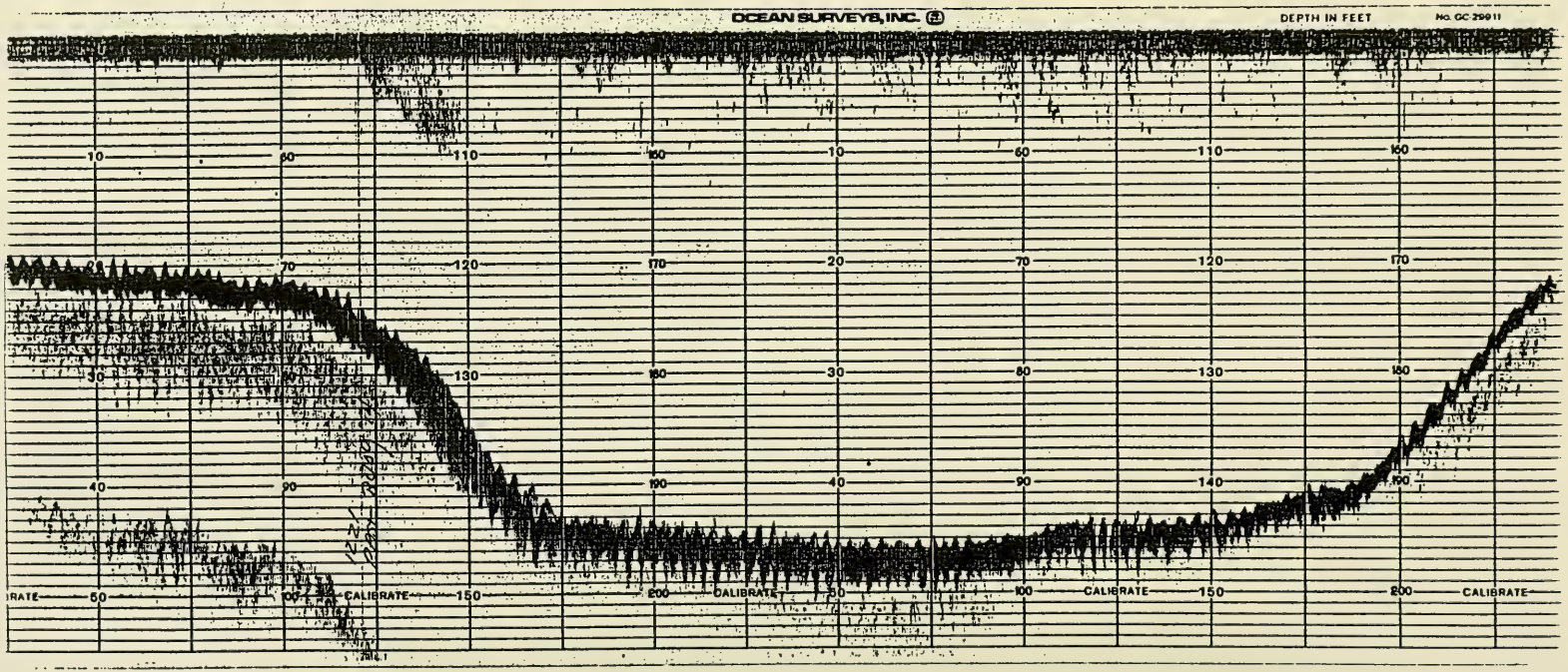
First of 4 segments for Transect #38 acoustic survey of 15 November 1993; profile runs east to west



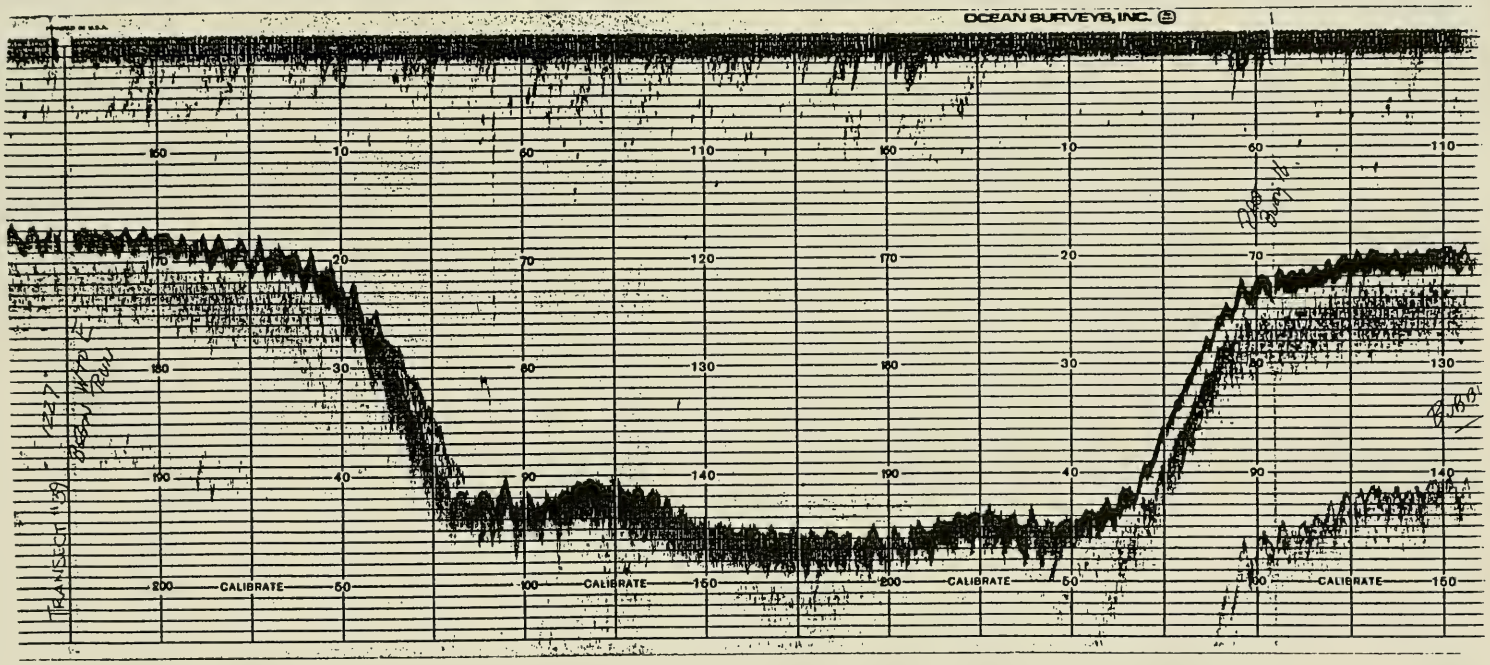
Second of 4 segments for Transect #38 acoustic survey of 15 November 1993; profile runs east to west



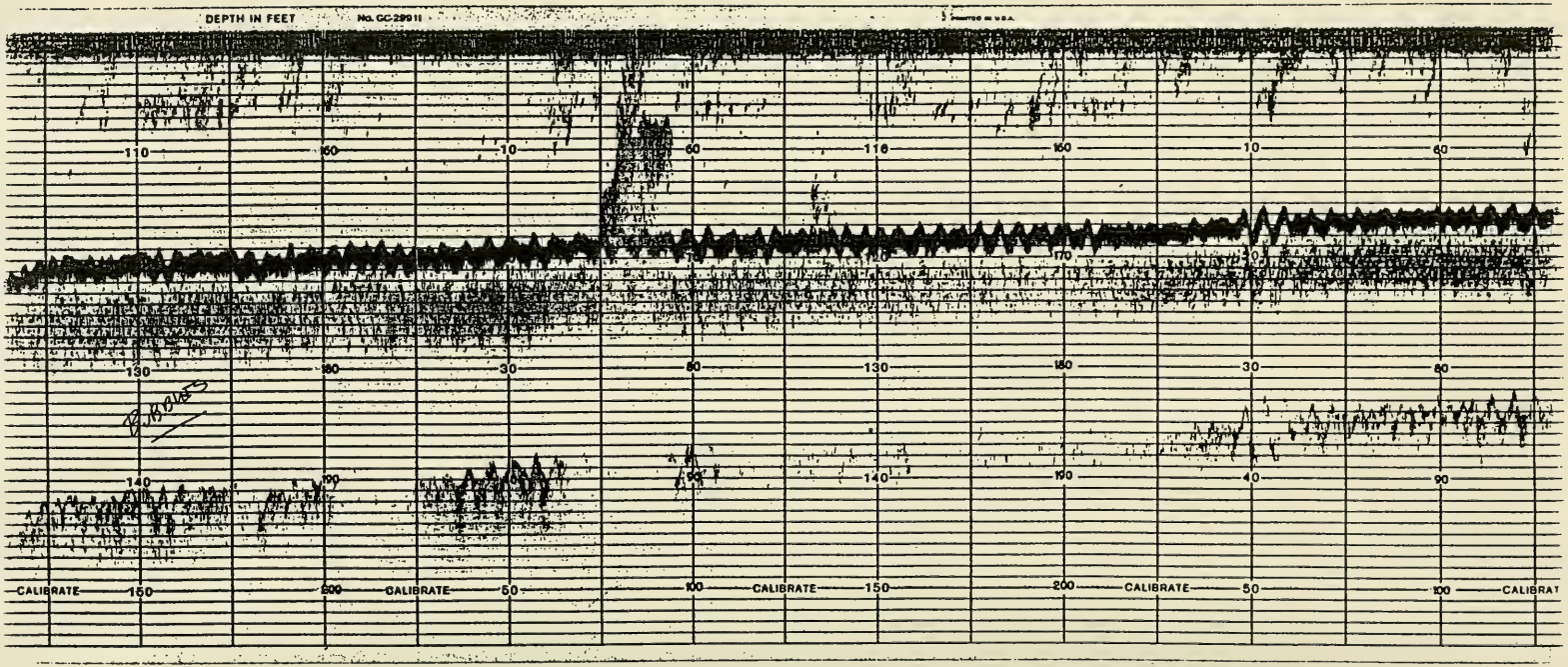
Third of 4 segments for Transect #38 acoustic survey of 15 November 1993; profile runs east to west



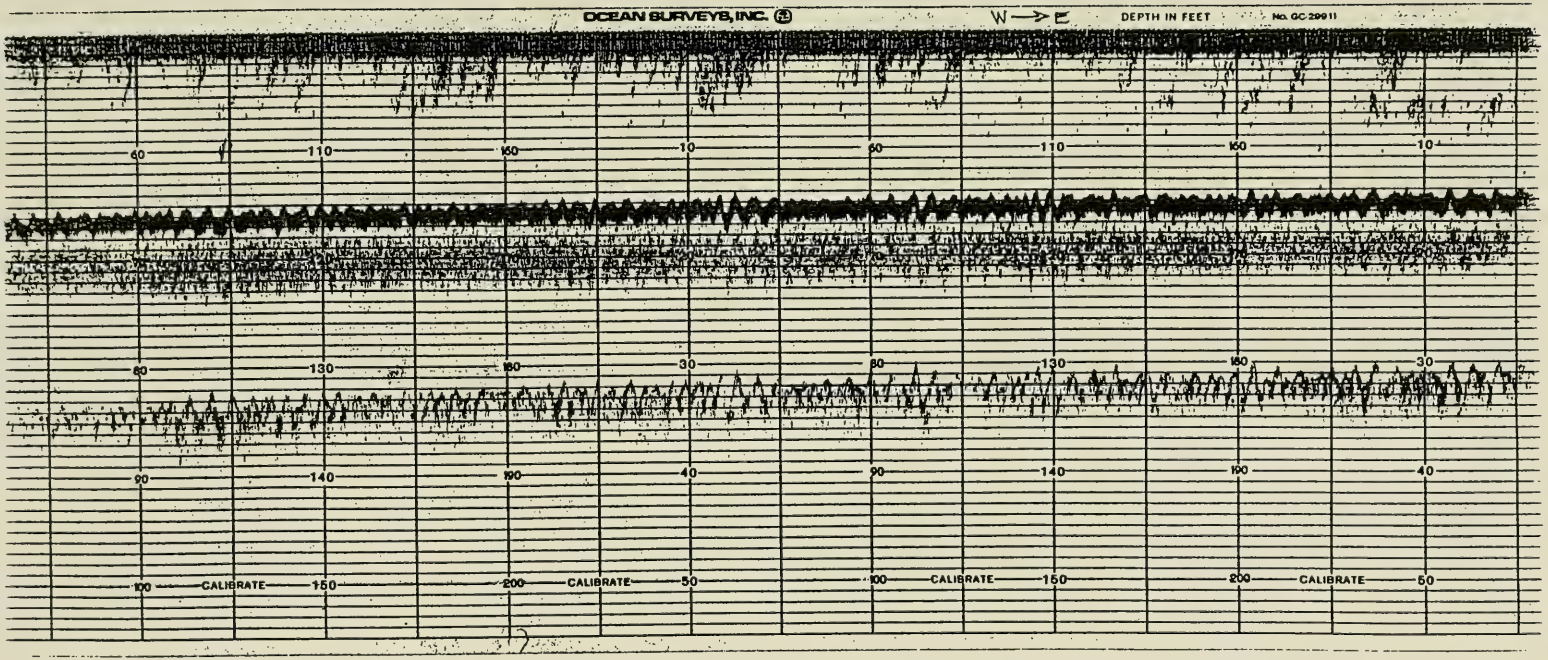
Fourth of 4 segments for Transect #38 acoustic survey of 15 November 1993; profile runs east to west



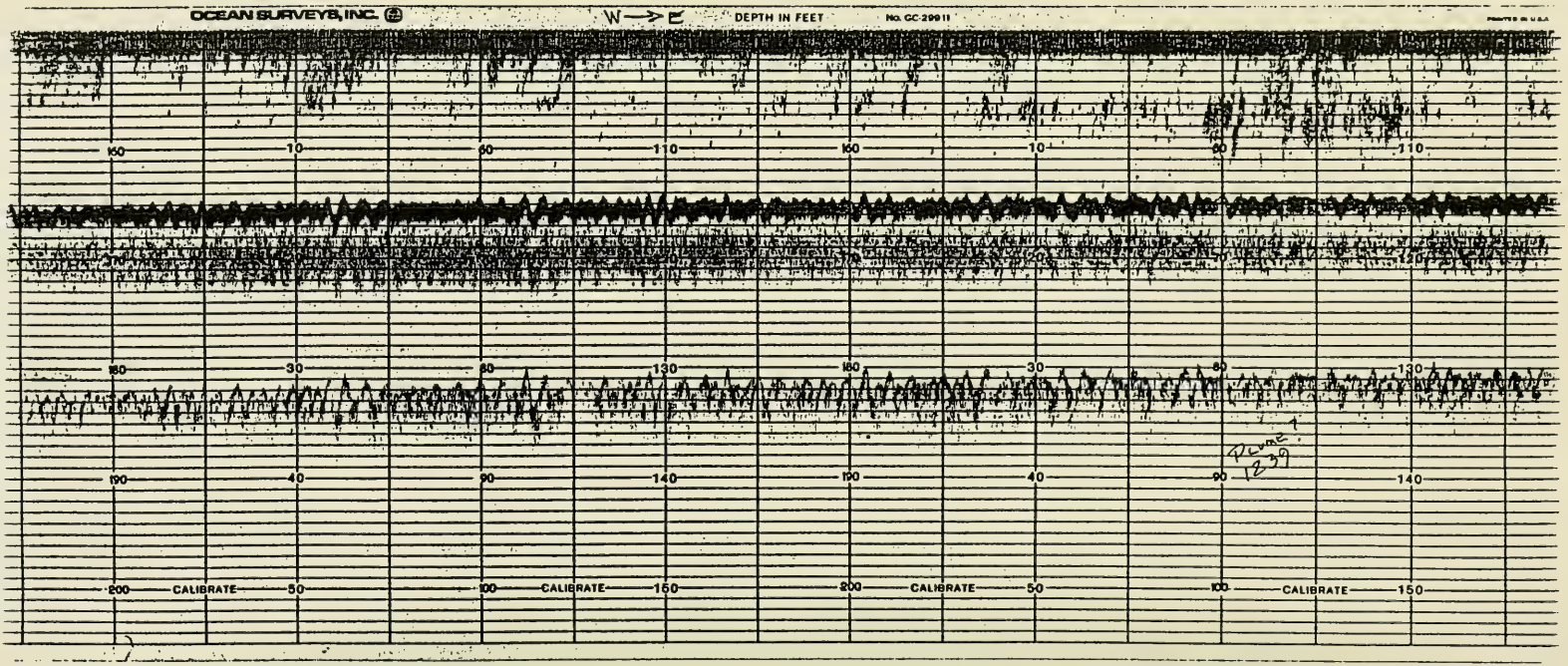
First of 5 segments for Transect #39 acoustic survey of 15 November 1993; profile runs west to east



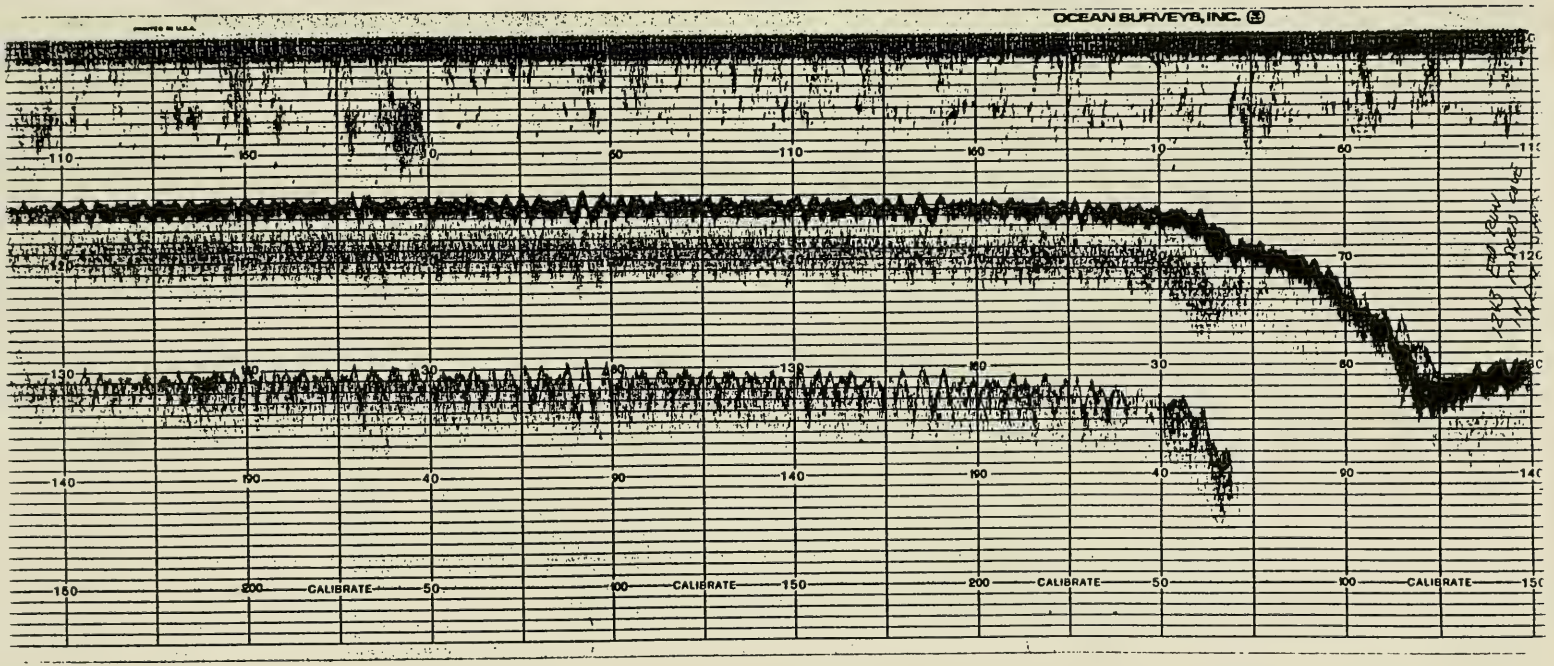
Second of 5 segments for Transect #39 acoustic survey of 15 November 1993; profile runs west to east



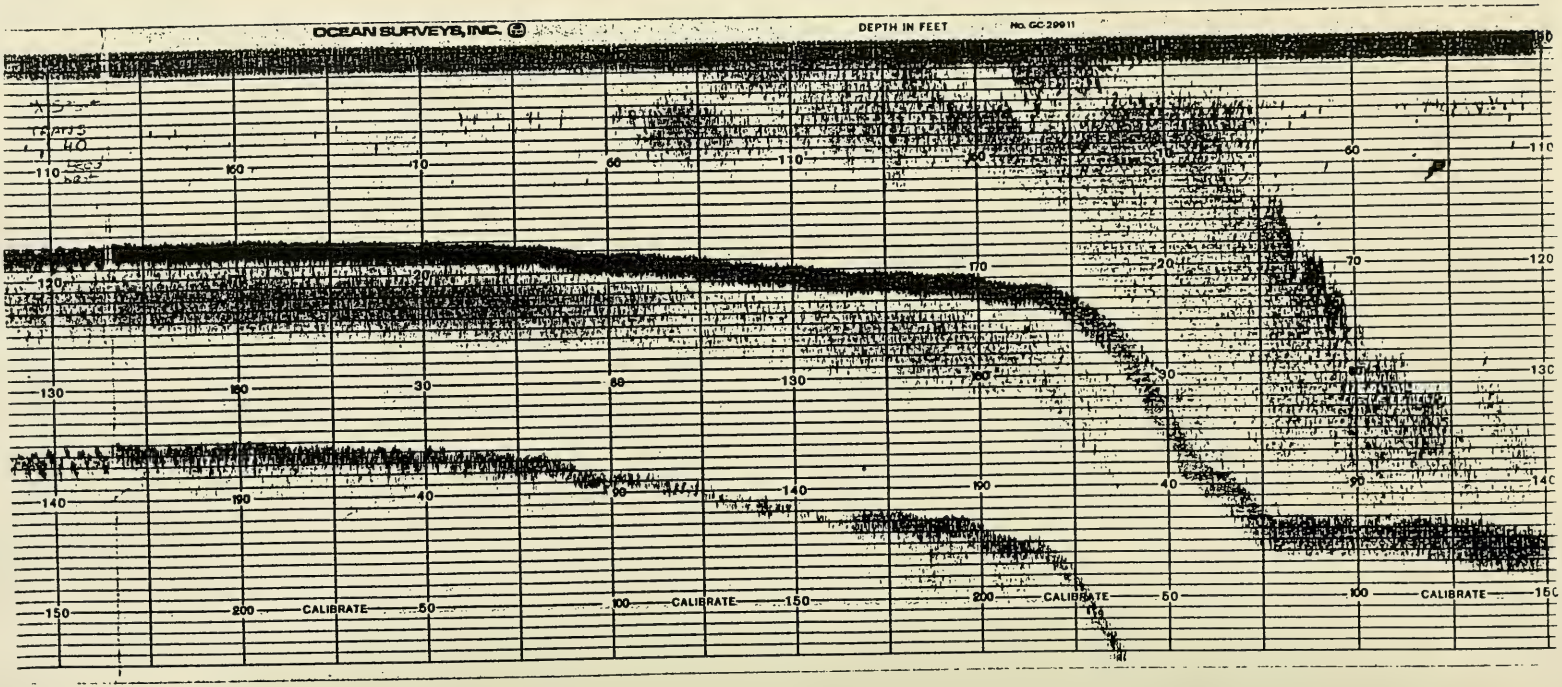
Third of 5 segments for Transect #39 acoustic survey of 15 November 1993; profile runs west to east



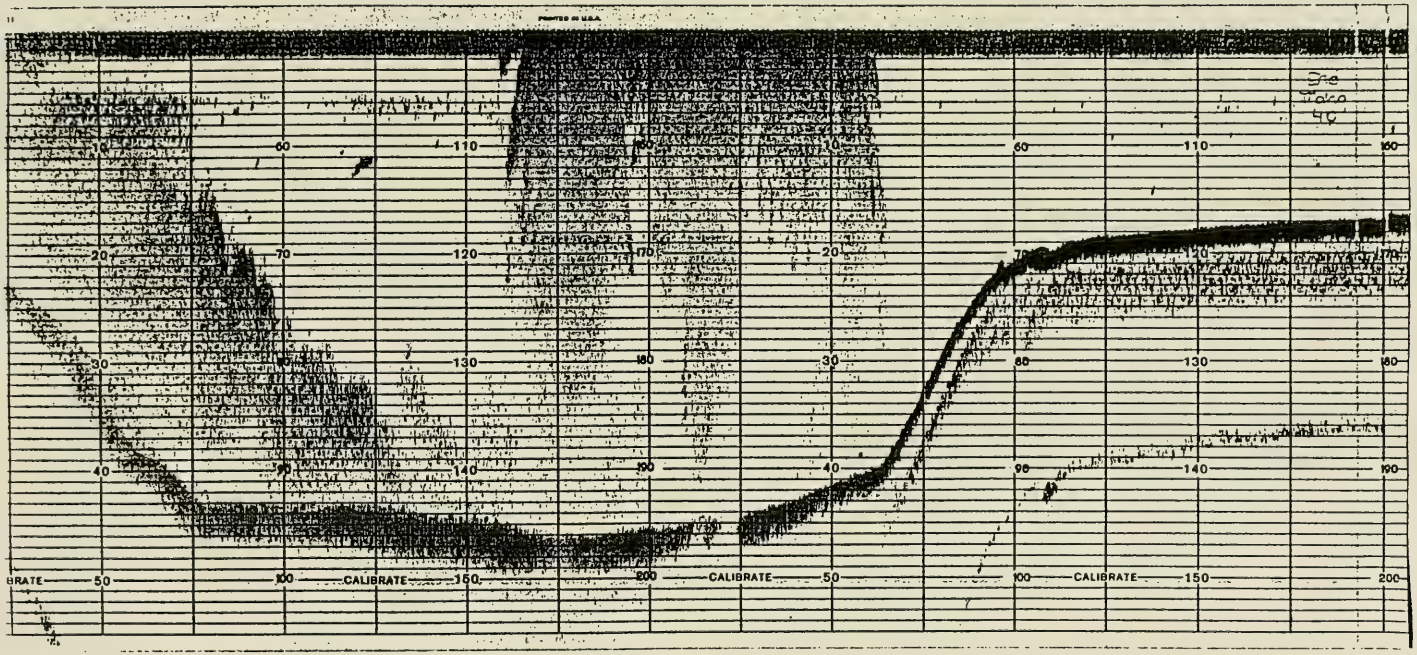
Fourth of 5 segments for Transect #39 acoustic survey of 15 November 1993; profile runs west to east



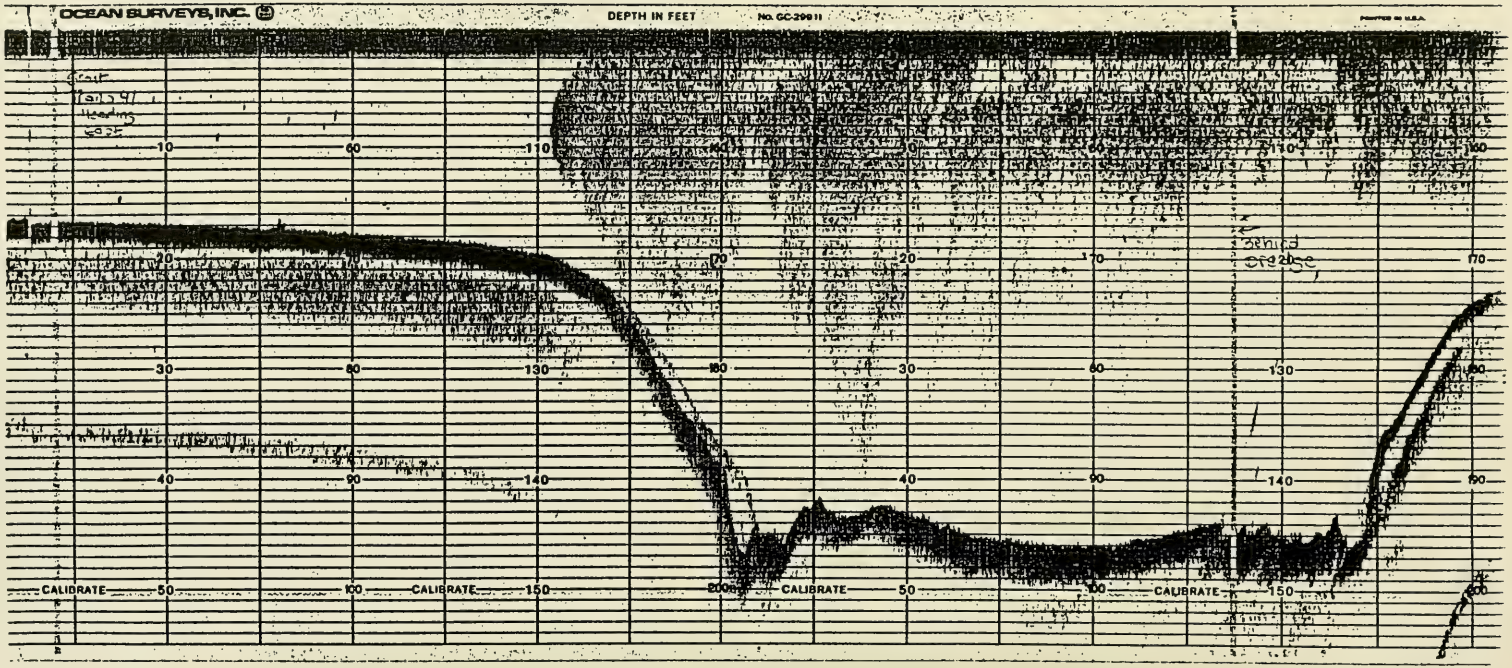
Fifth of 5 segments for Transect #39 acoustic survey of 15 November 1993; profile runs west to east



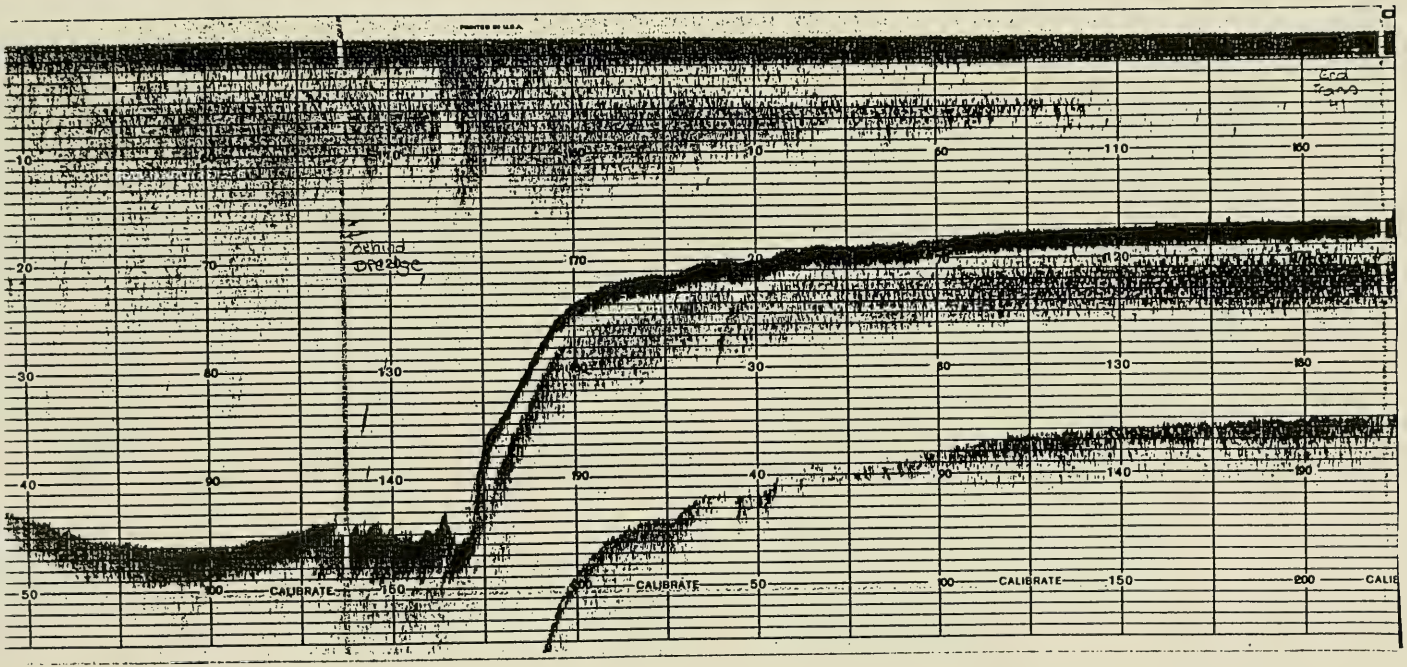
Beginning segment of Transect #40 acoustic survey of 16 November 1993; profile runs east to west



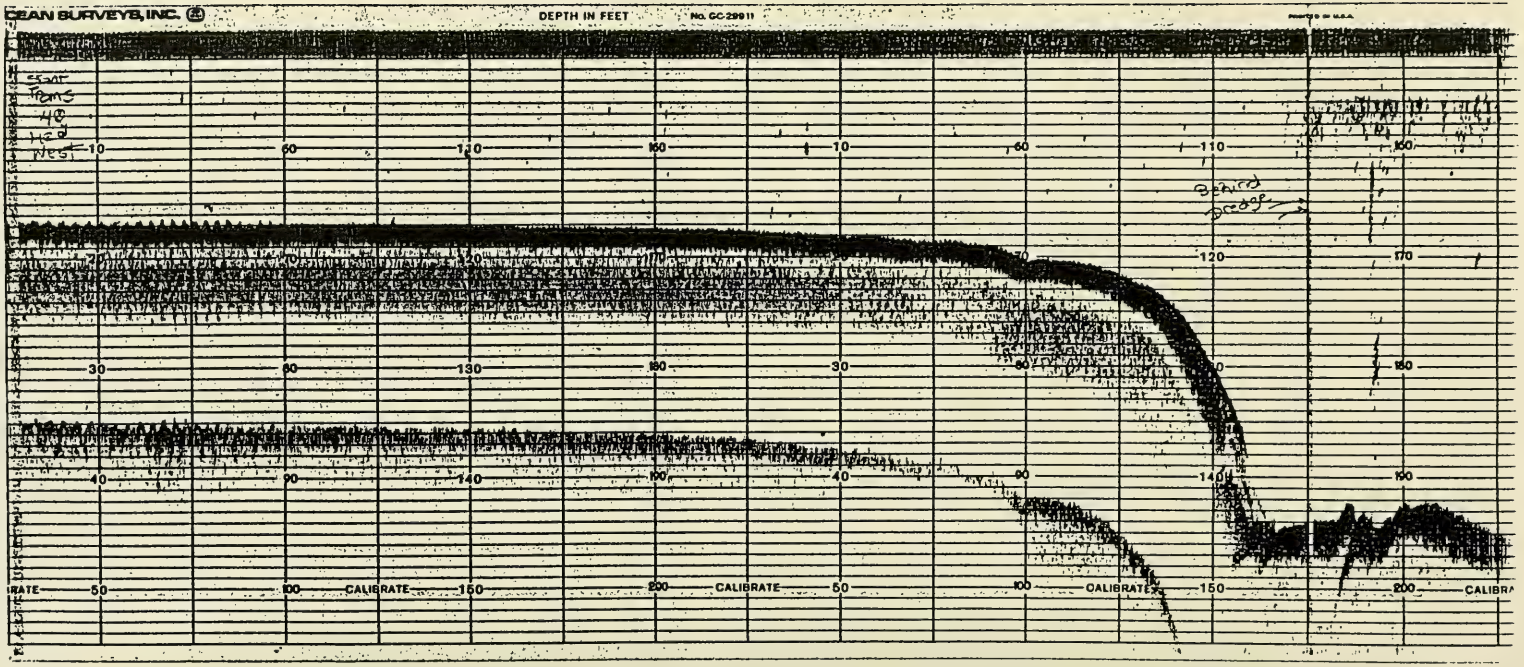
End segment of Transect #40 acoustic survey of 16 November 1993; profile runs east to west



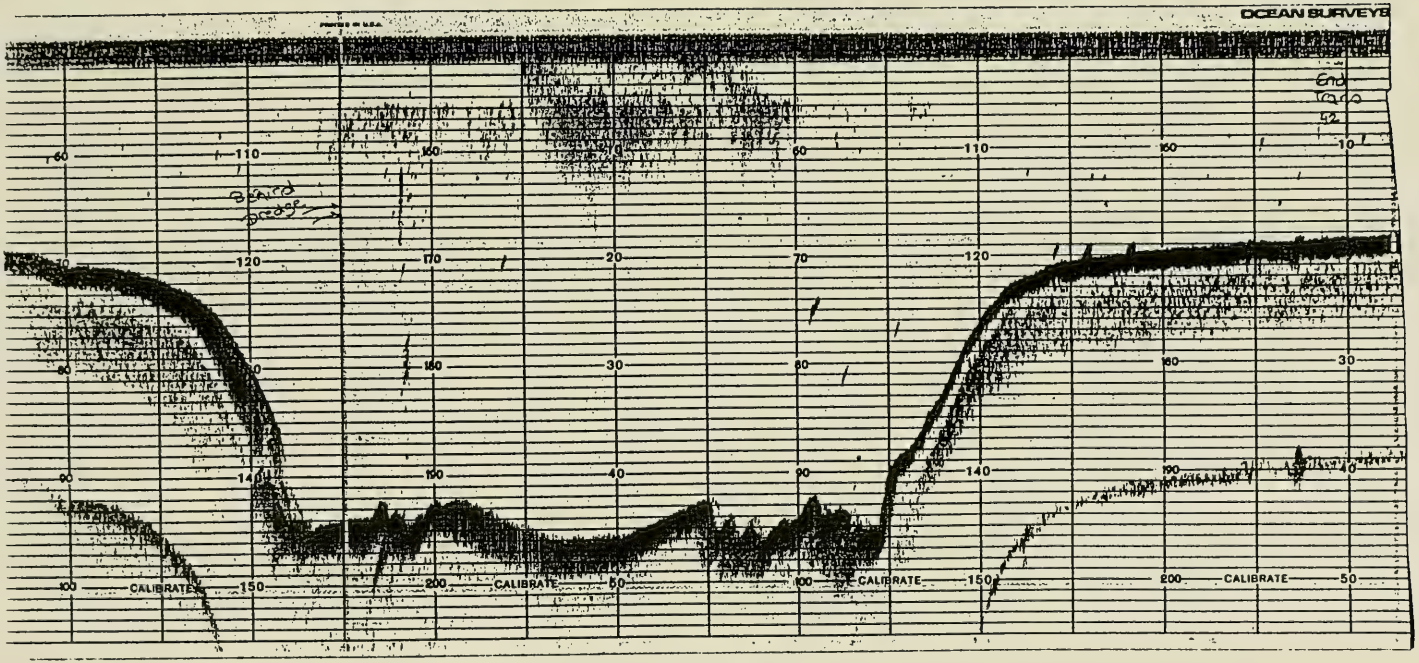
Beginning segment of Transect #41 acoustic survey of 16 November 1993; profile runs west to east



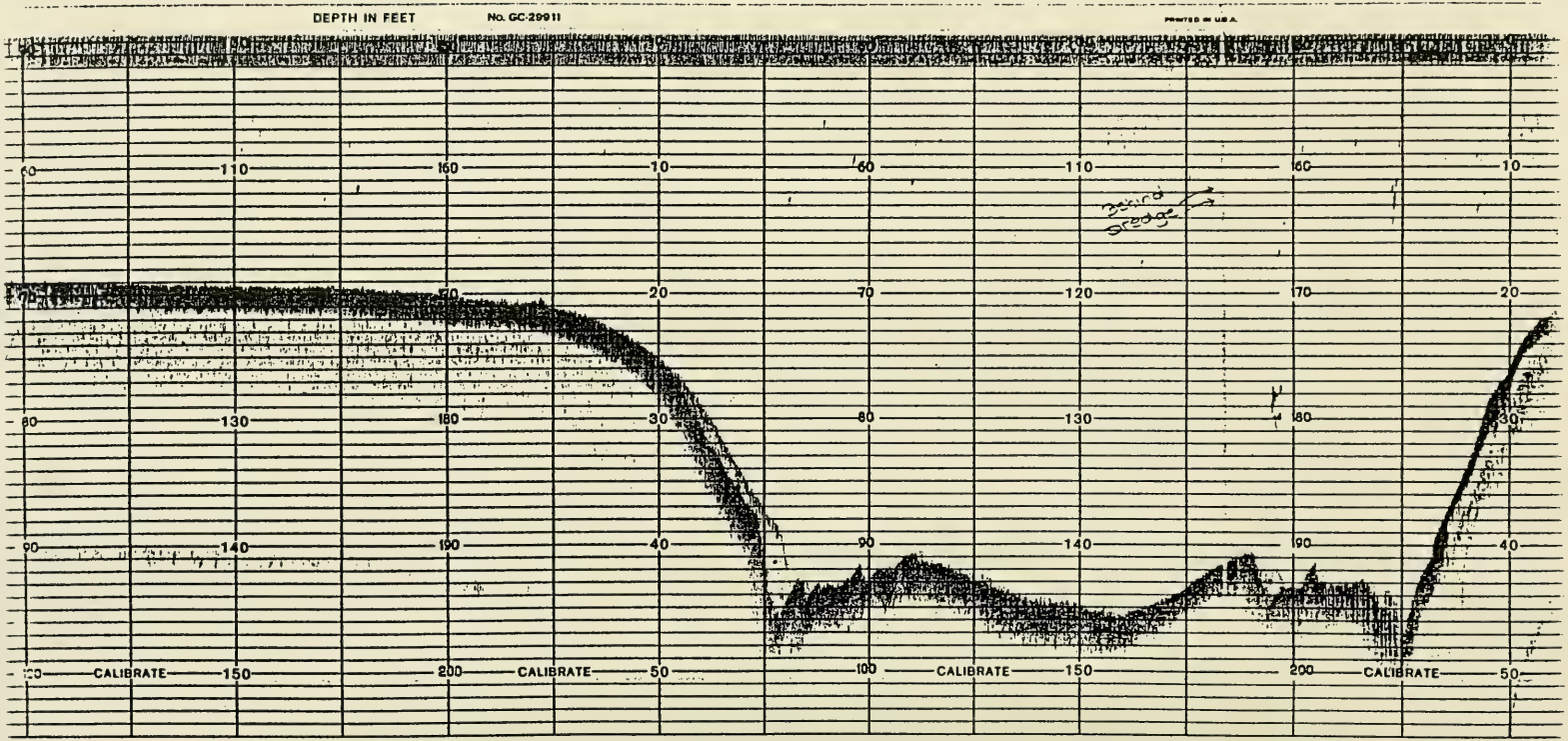
End segment of Transect #41 acoustic survey of 16 November 1993; profile runs west to east



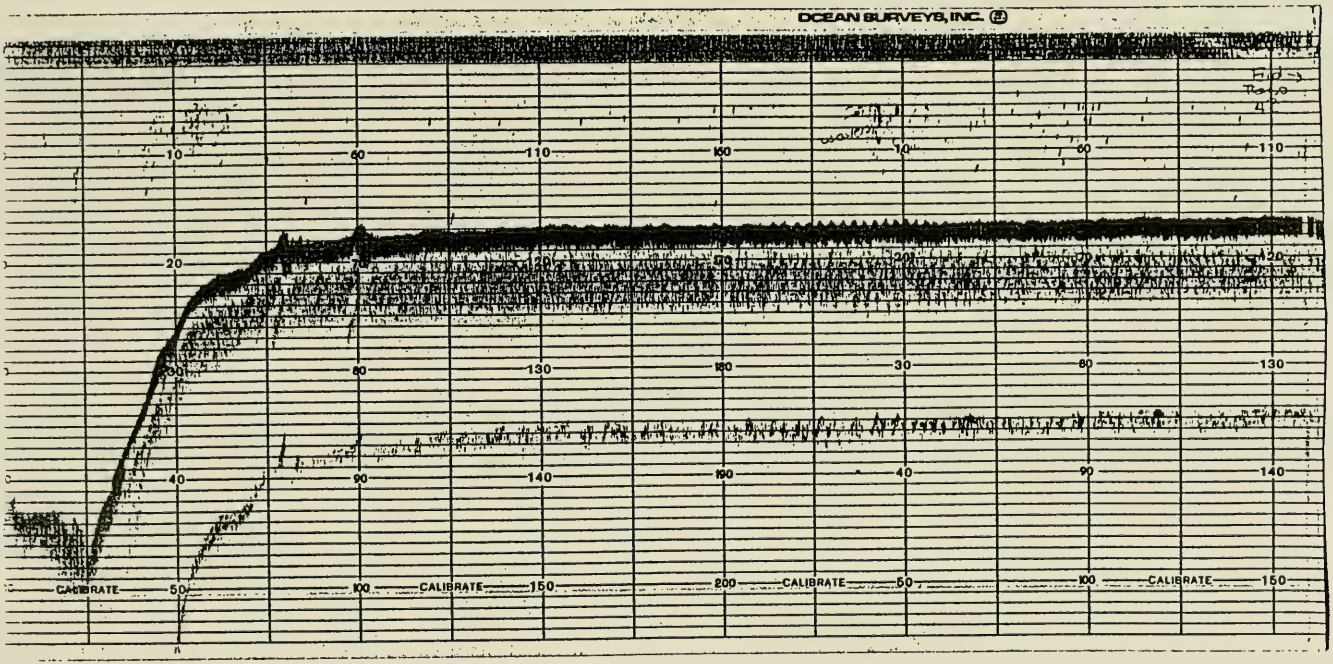
Beginning segment of Transect #42 acoustic survey of 16 November 1993; profile runs east to west



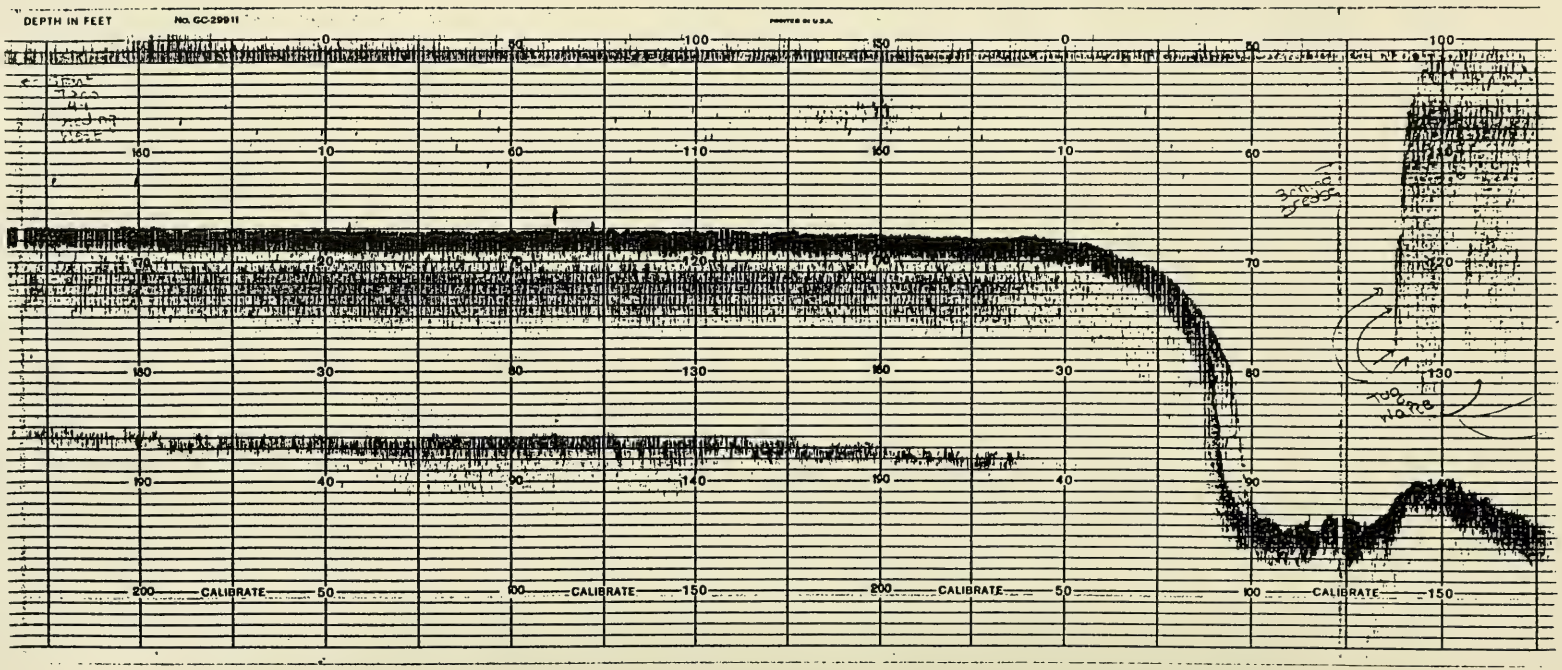
End segment of Transect #42 acoustic survey of 16 November 1993; profile runs east to west



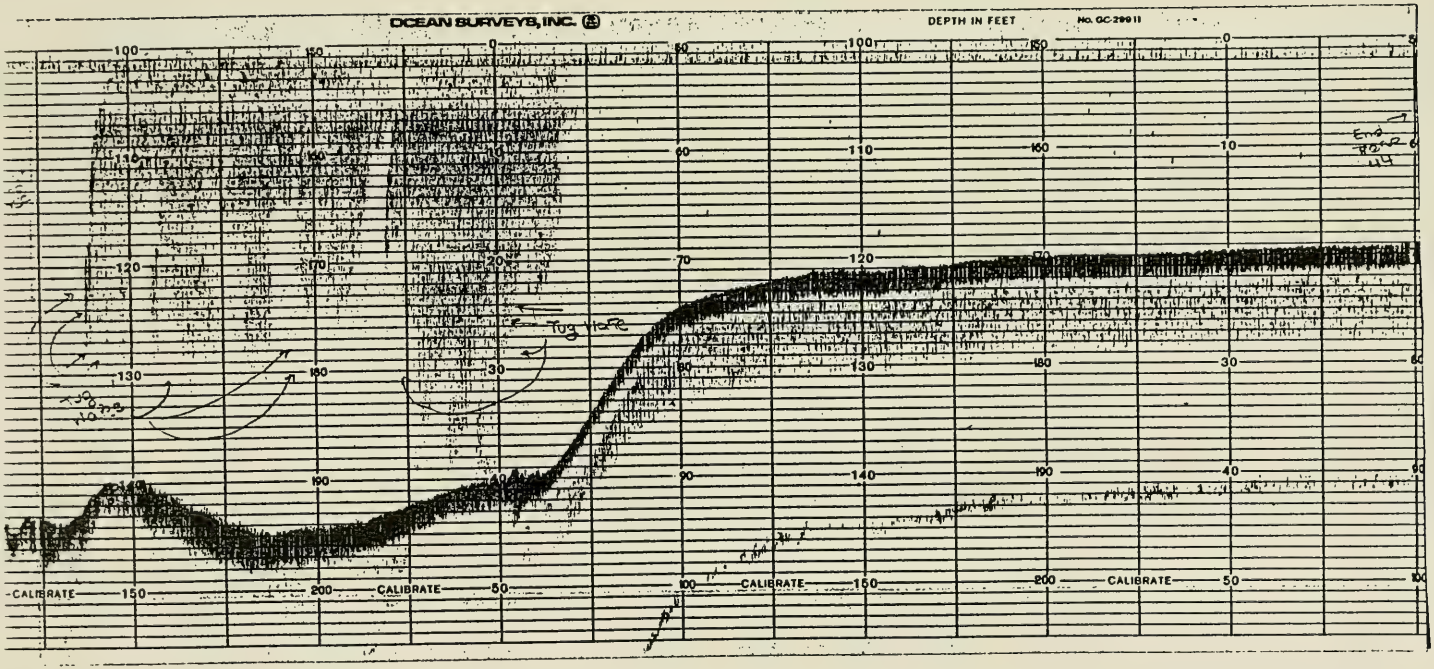
Beginning segment of Transect #43 acoustic survey of 16 November 1993; profile runs west to east



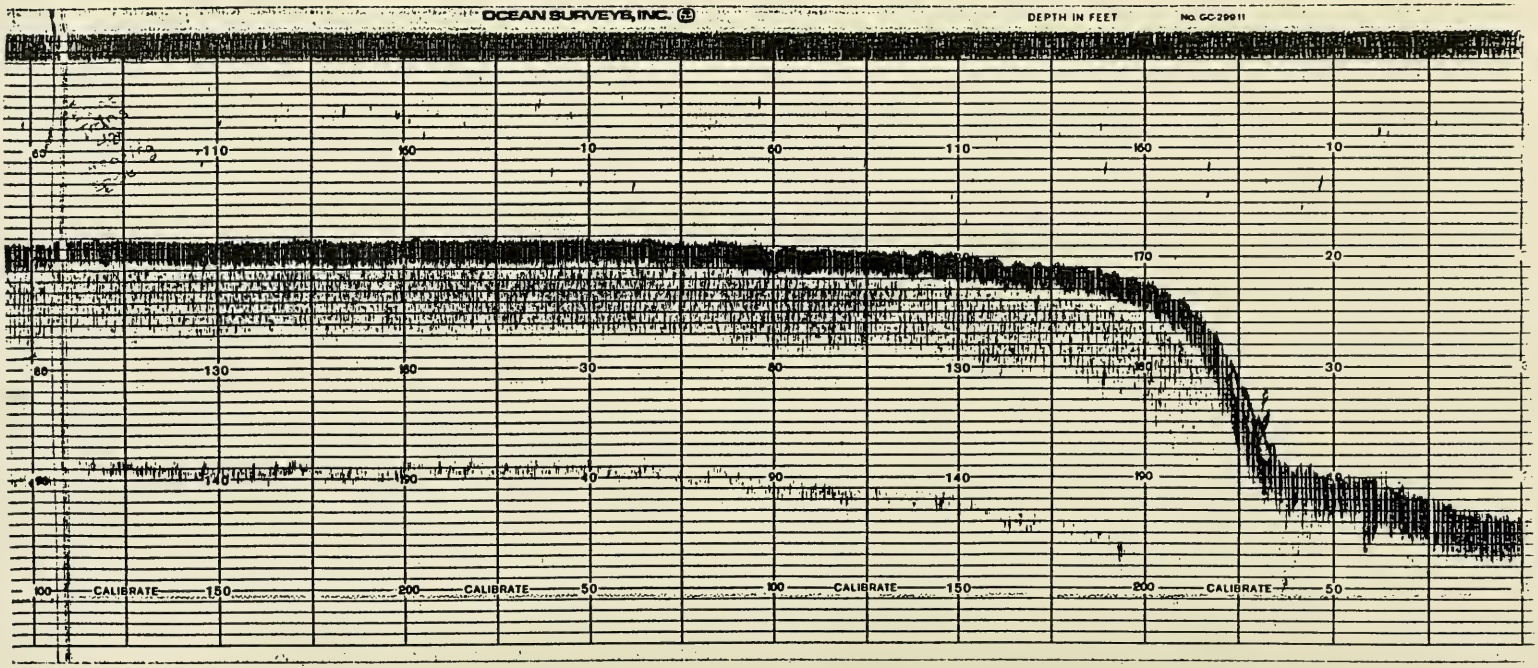
End segment of Transect #43 acoustic survey of 16 November 1993; profile runs west to east



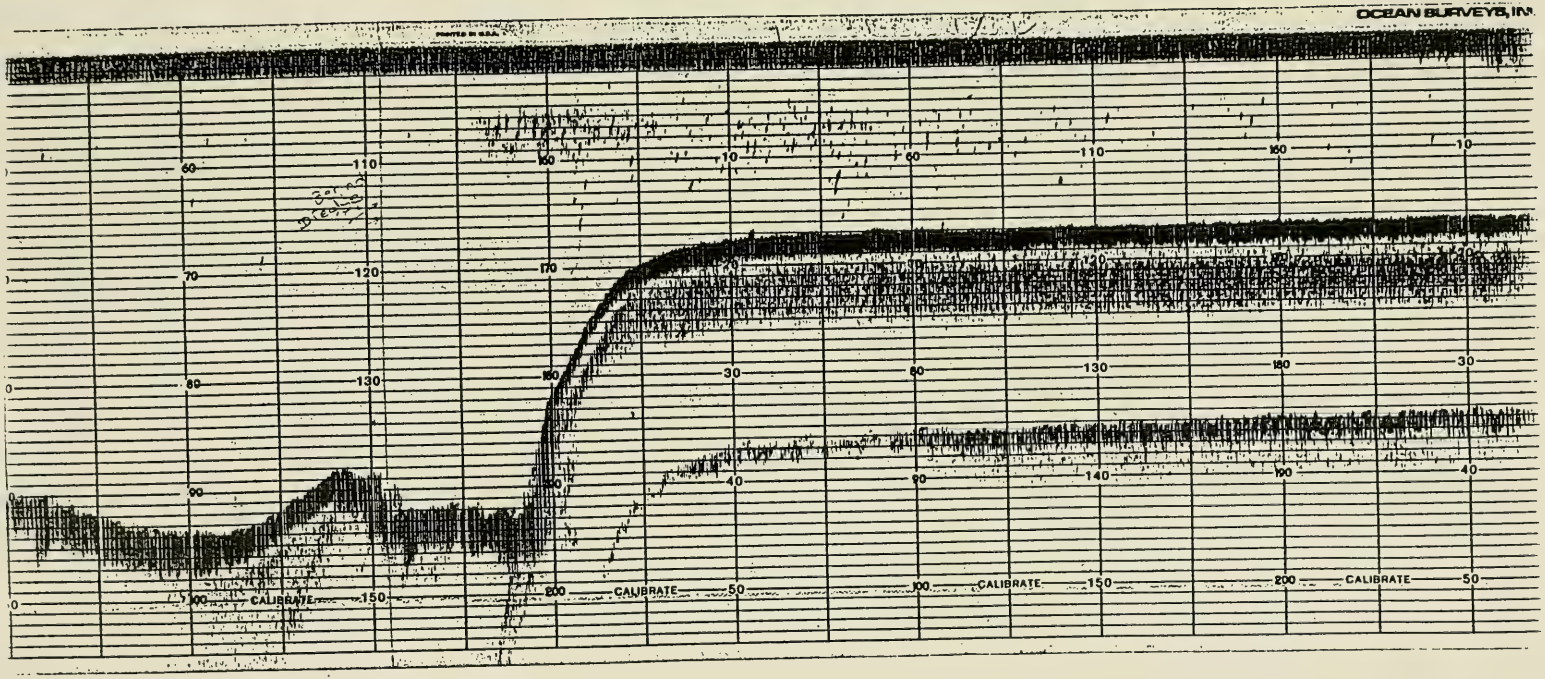
Beginning segment of Transect #44 acoustic survey of 16 November 1993; profile runs east to west



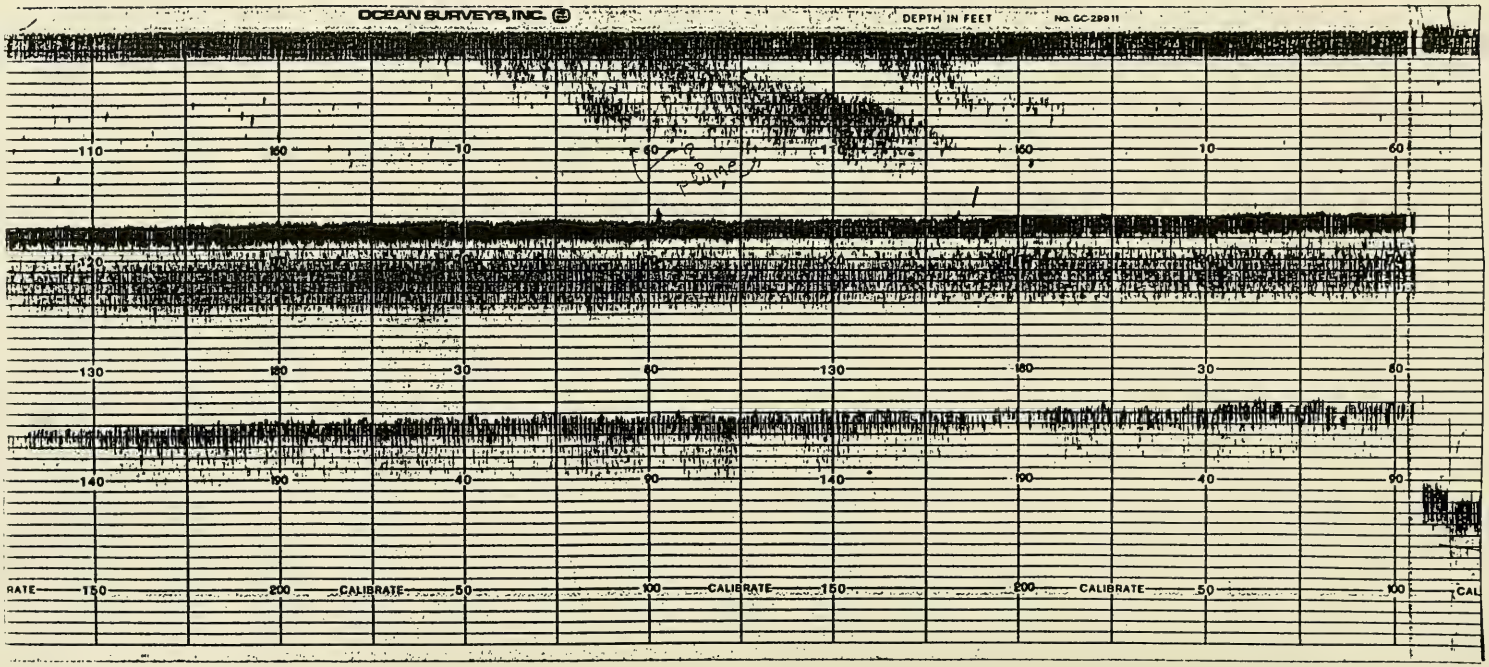
End segment of Transect #44 acoustic survey of 16 November 1993; profile runs east to west



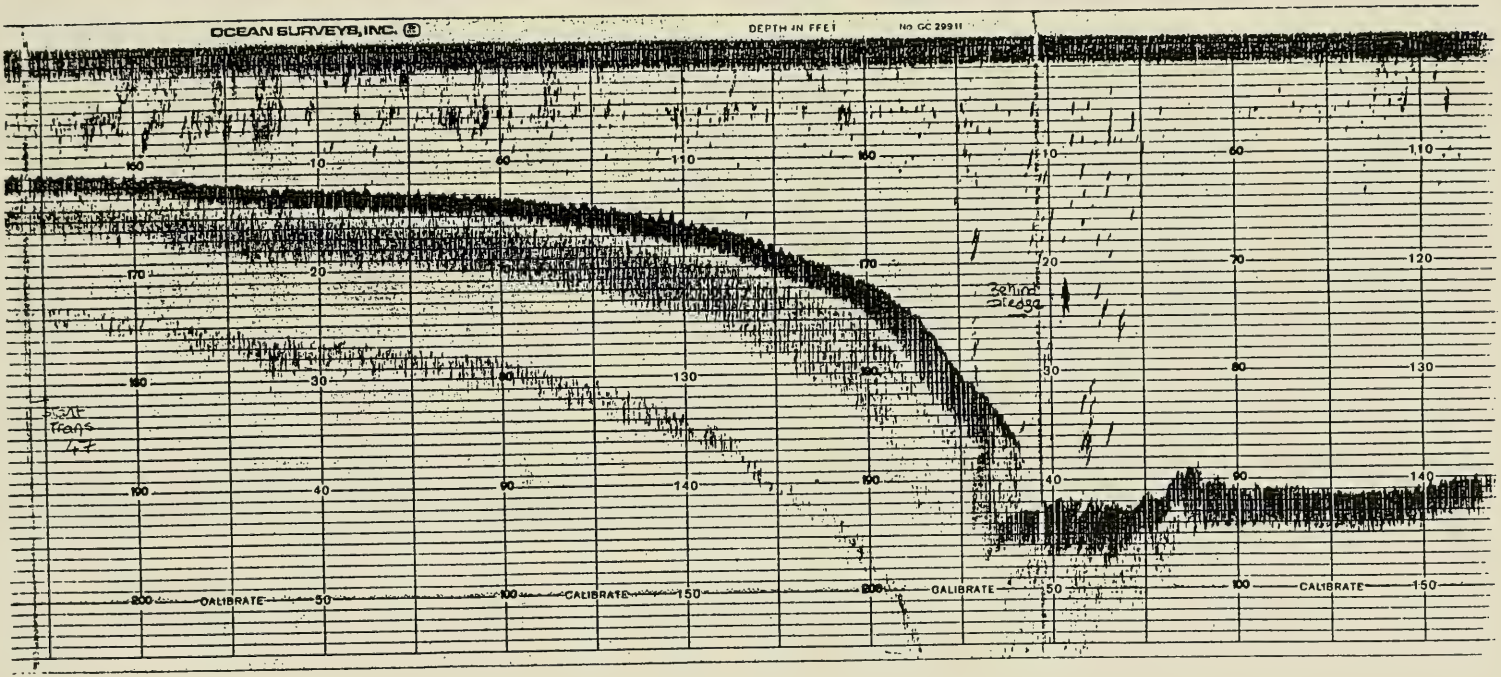
Beginning segment of Transect #46 acoustic survey of 16 November 1993; profile runs west to east



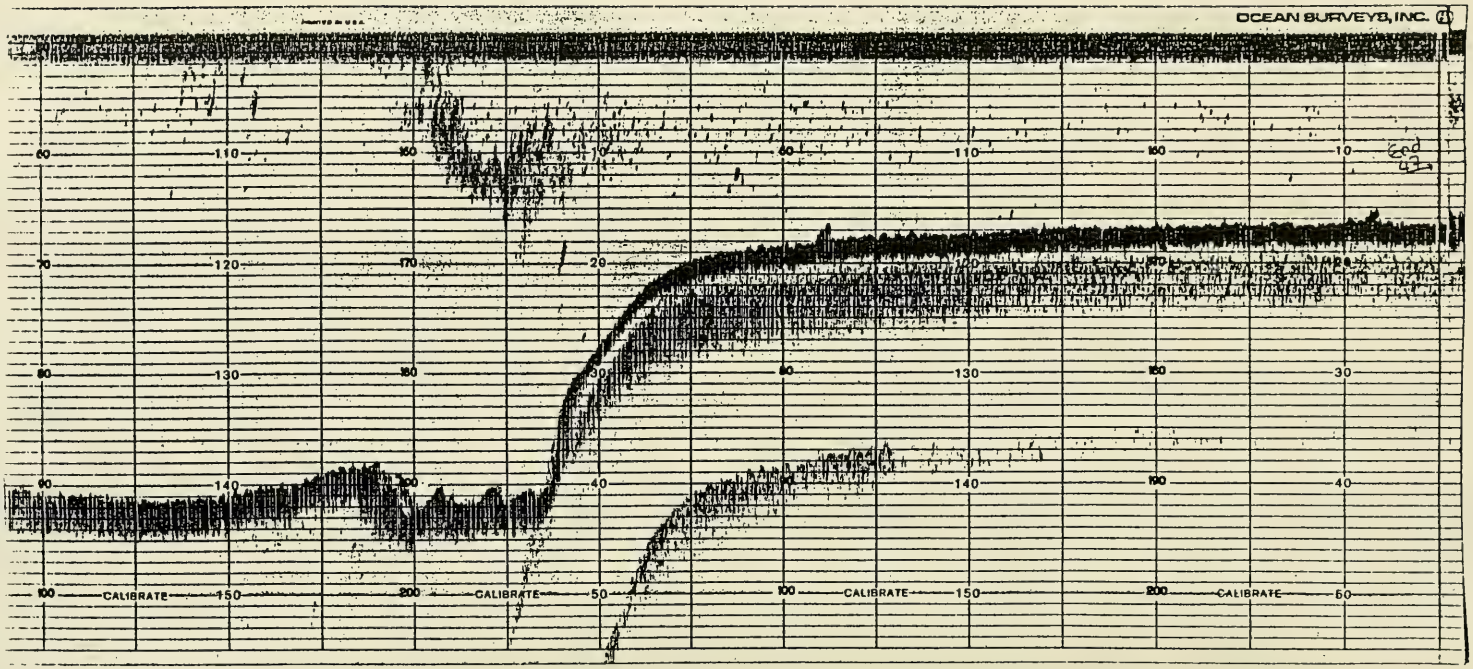
Middle segment of Transect #46 acoustic survey of 16 November 1993; profile runs west to east



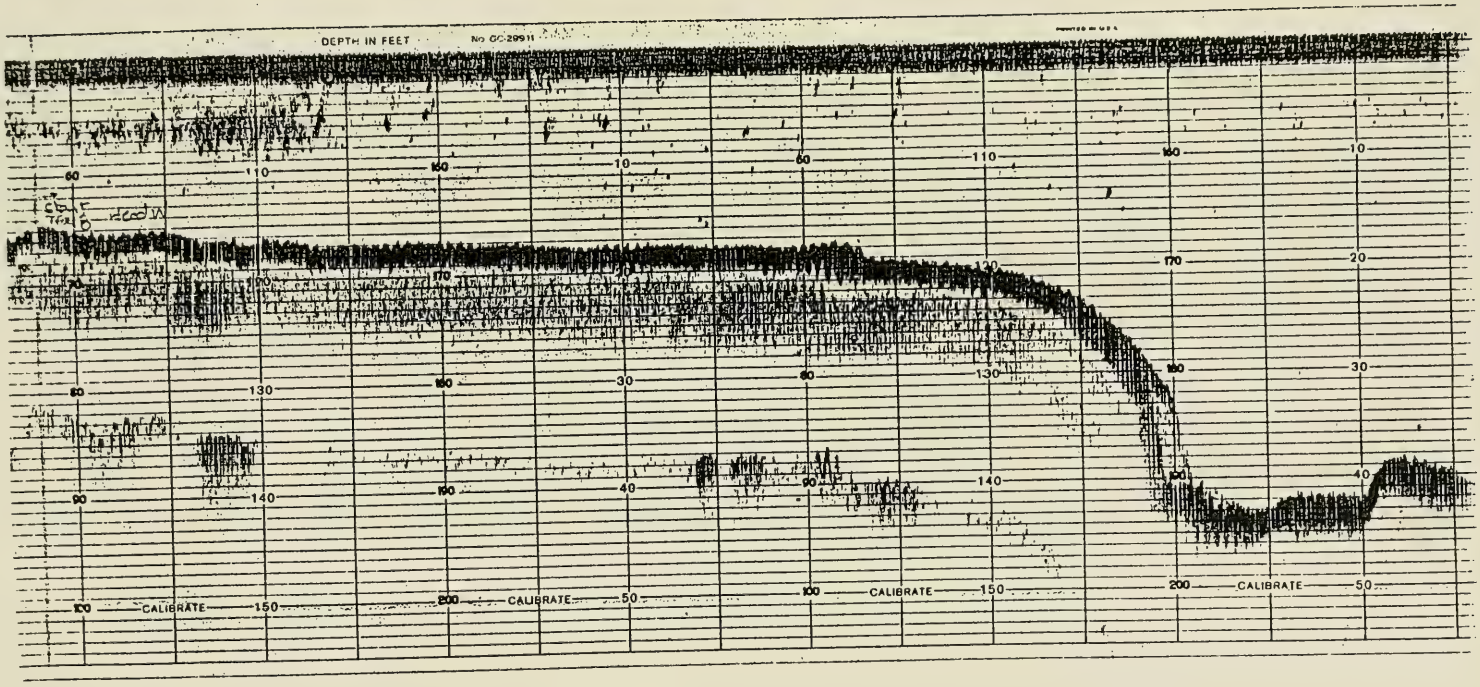
End segment of Transect #46 acoustic survey of 16 November 1993; profile runs west to east



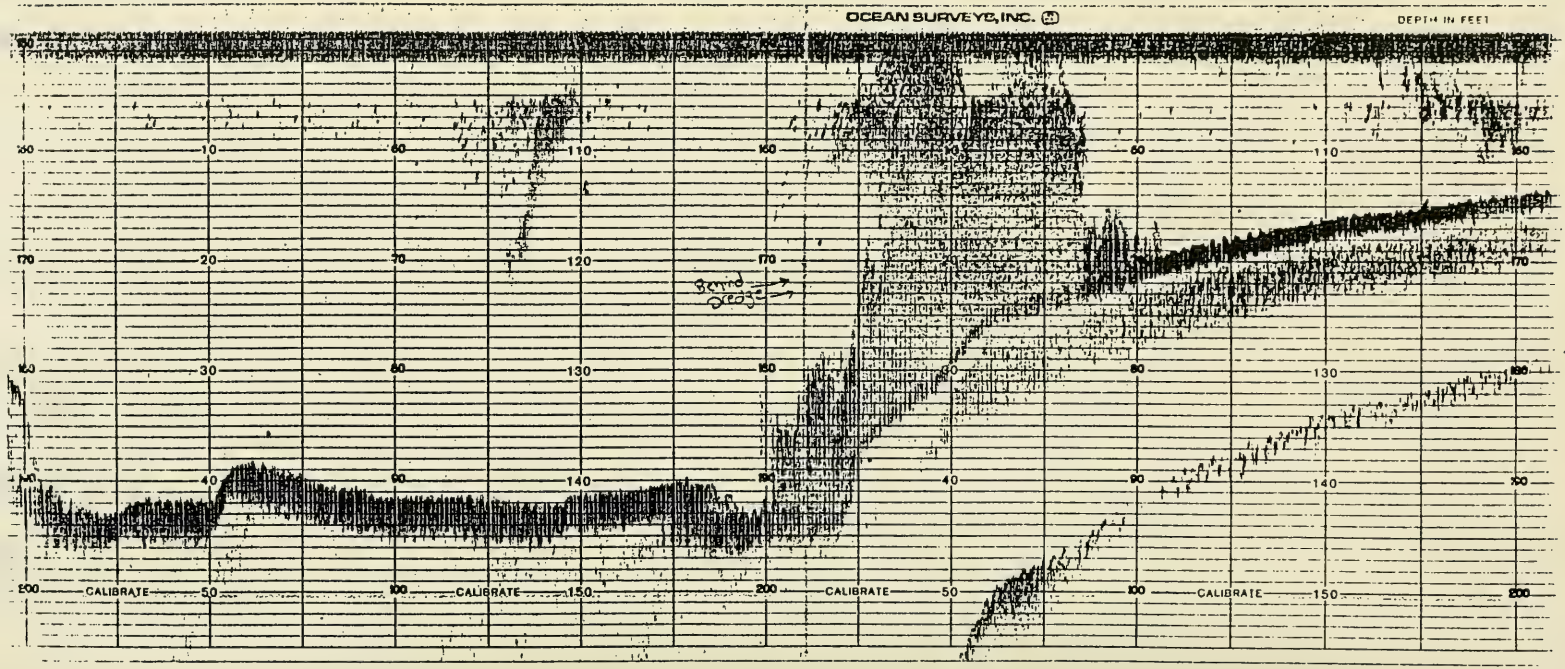
Beginning segment of Transect #47 acoustic survey of 18 November 1993; profile runs west to east



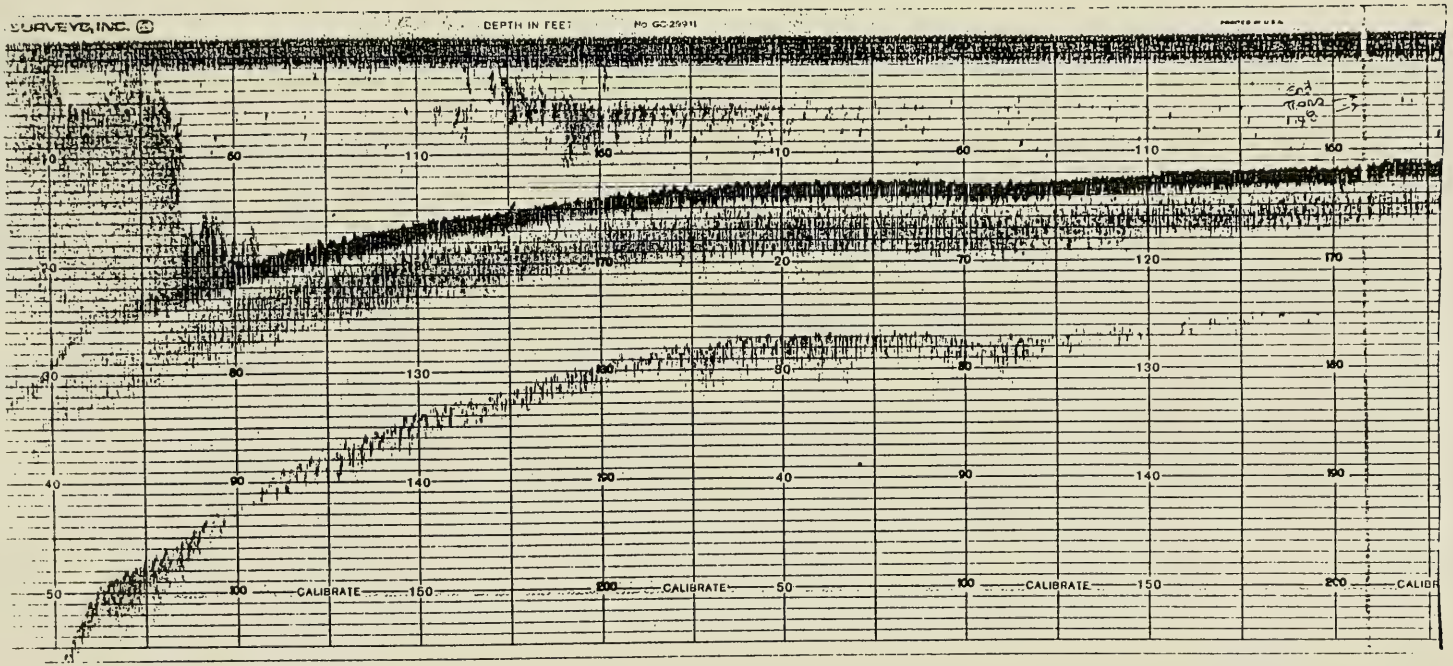
End segment of Transect #47 acoustic survey of 18 November 1993; profile runs west to east



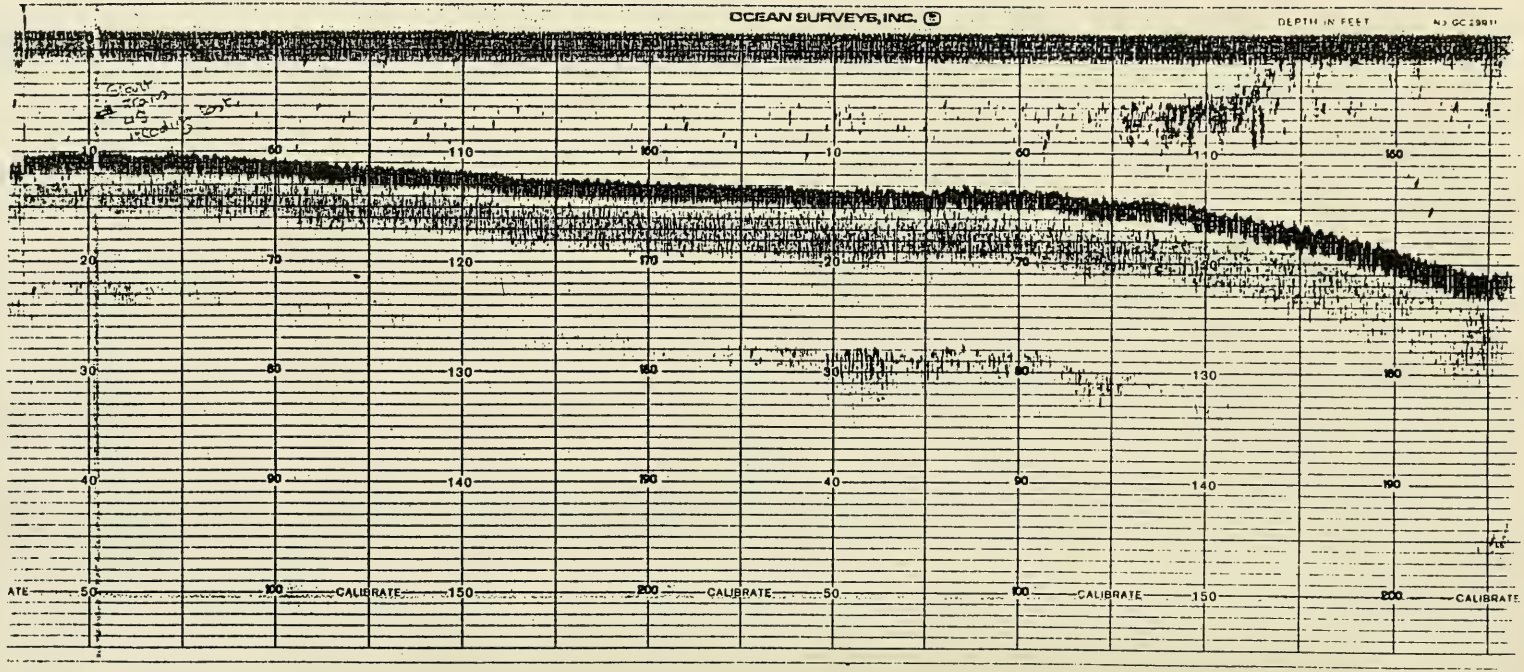
Beginning segment of Transect #48 acoustic survey of 18 November 1993; profile runs east to west



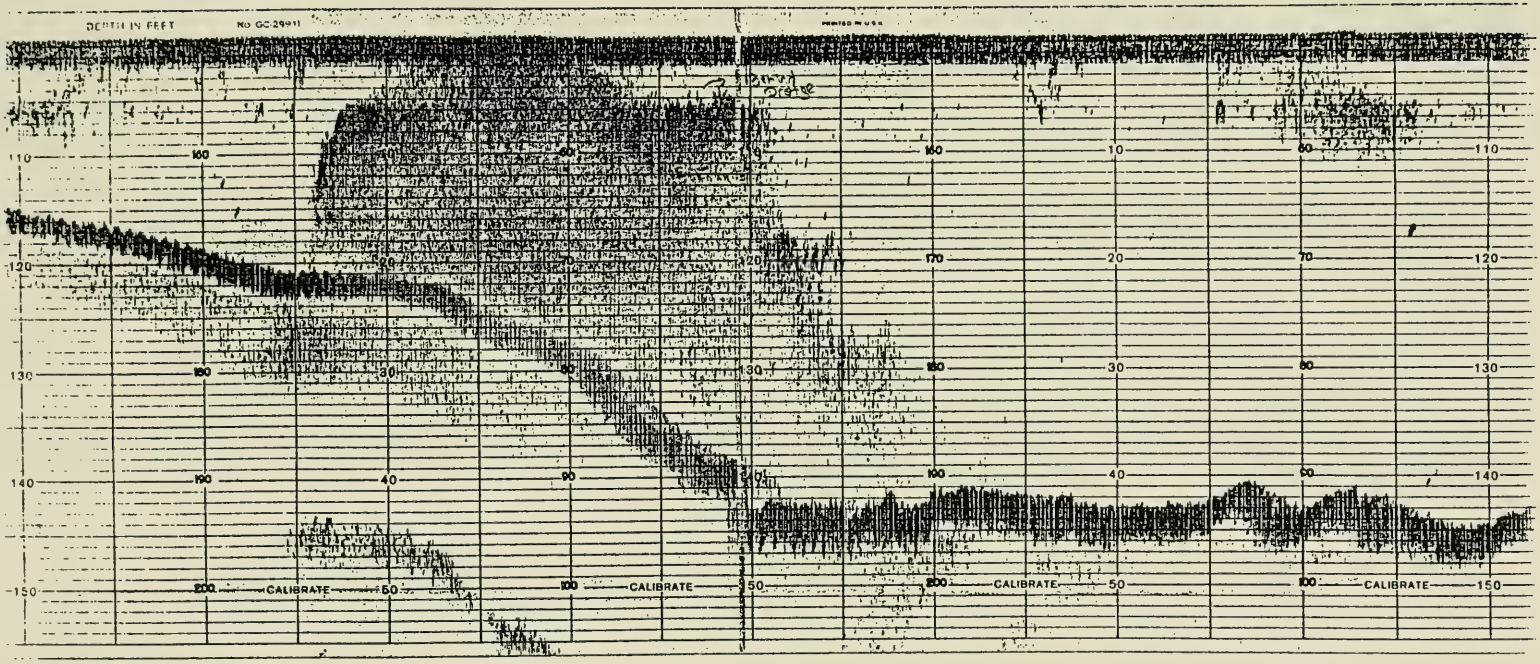
Middle segment of Transect #48 acoustic survey of 18 November 1993; profile runs east to west



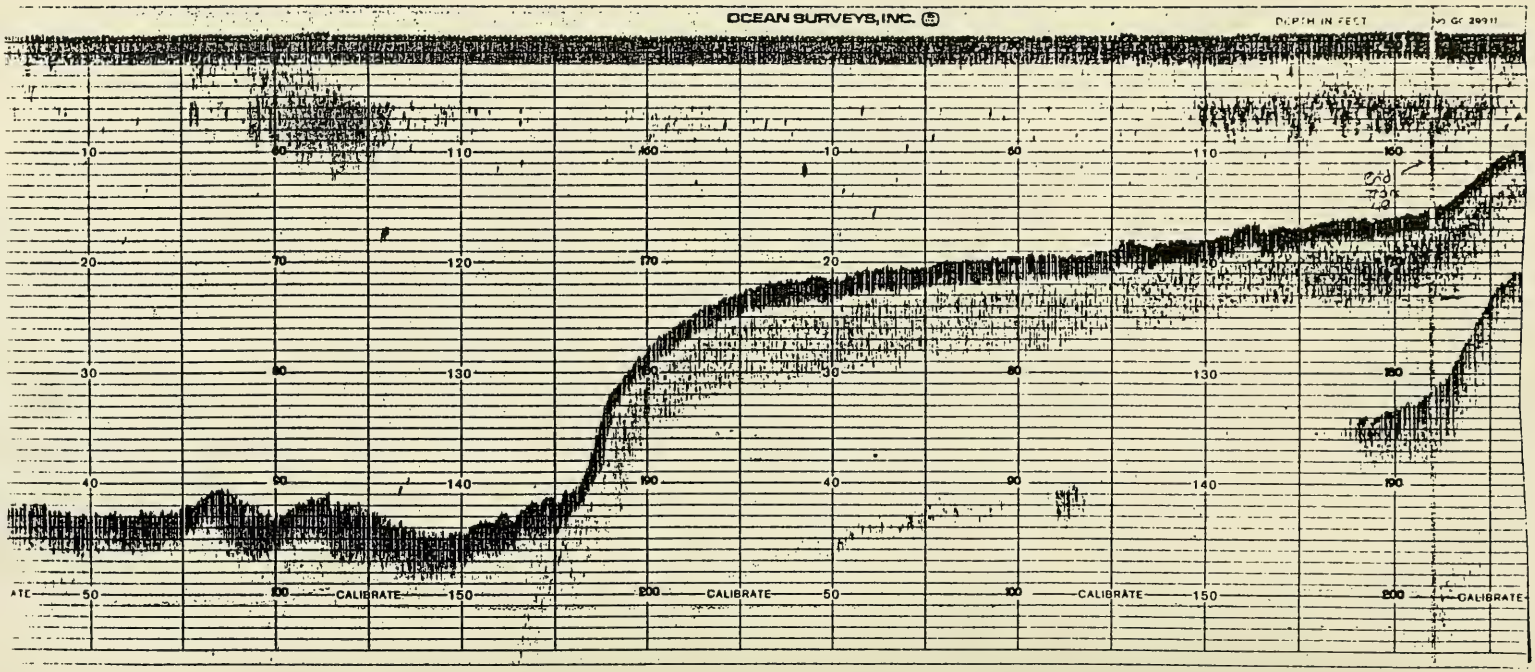
End segment of Transect #48 acoustic survey of 18 November 1993; profile runs east to west



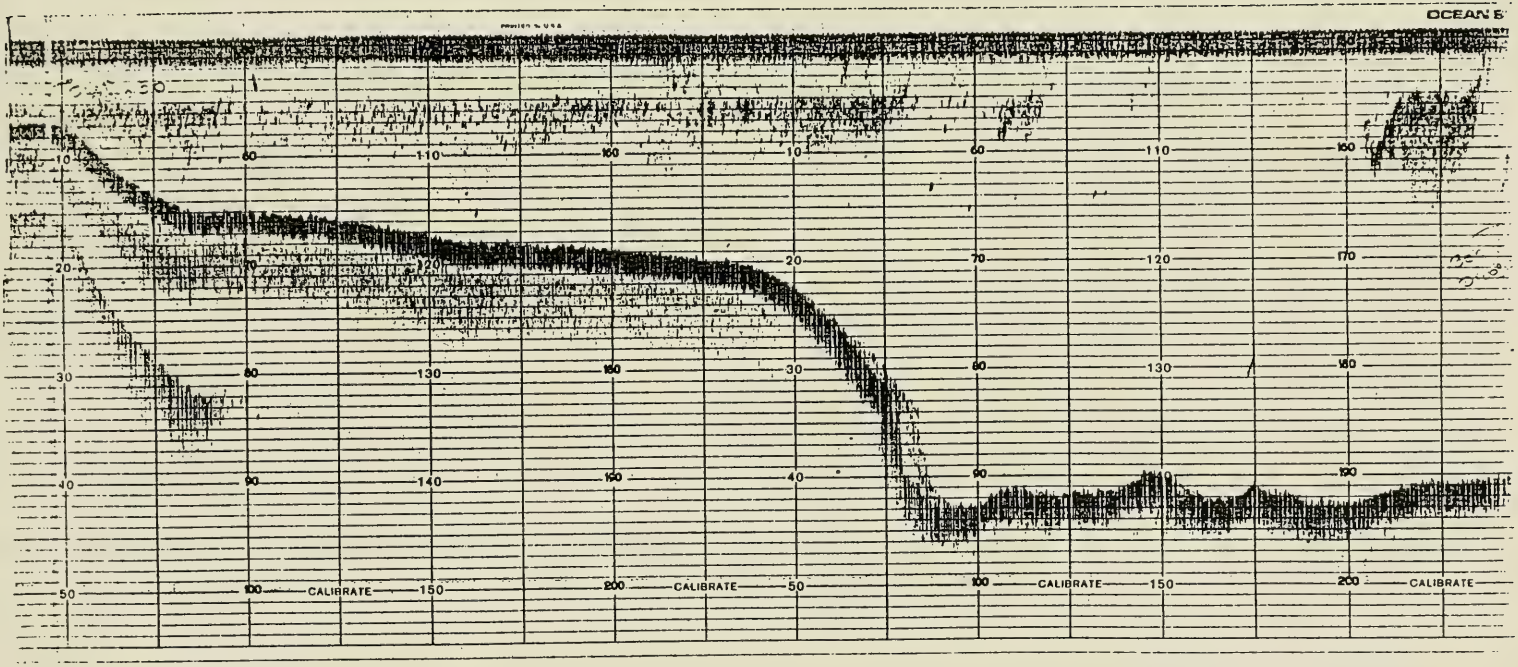
Beginning segment of Transect #49 acoustic survey of 18 November 1993; profile runs west to east



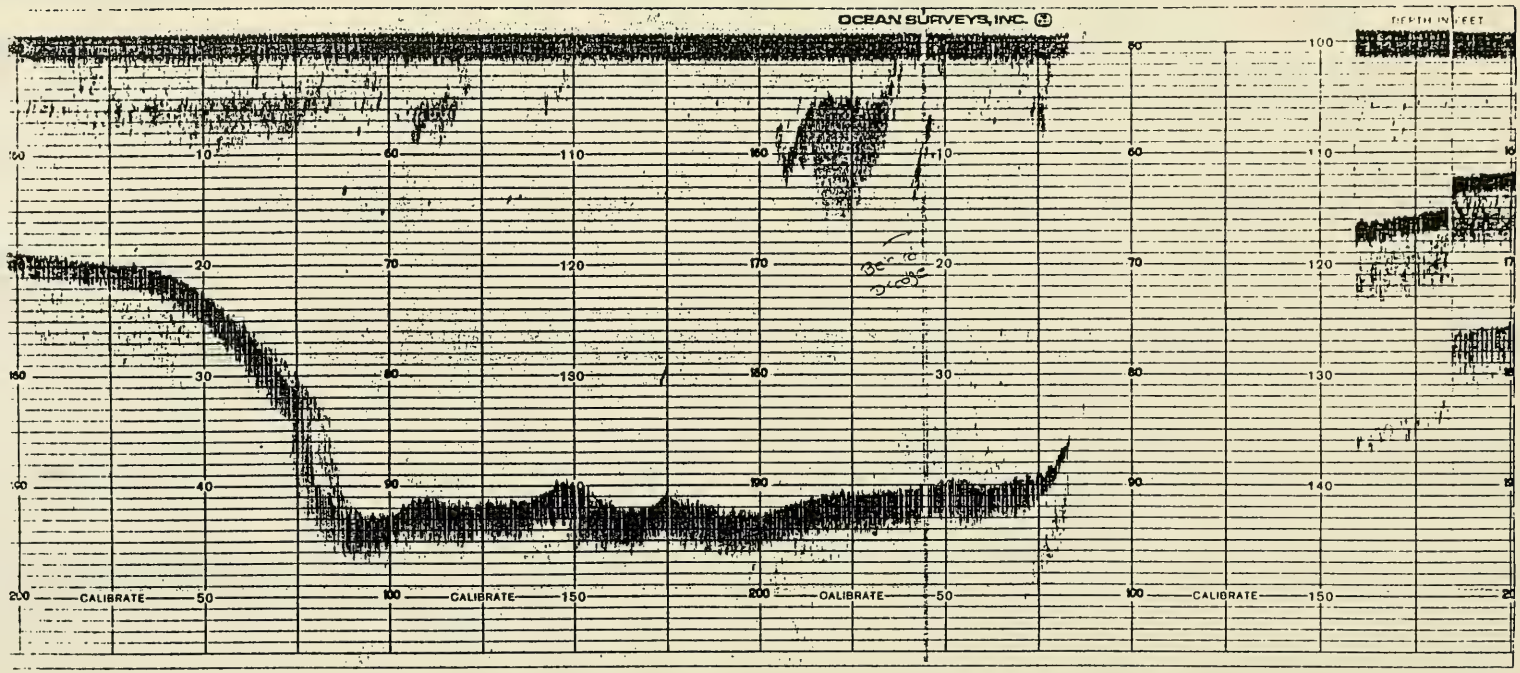
Middle segment of Transect #49 acoustic survey of 18 November 1993; profile runs west to east



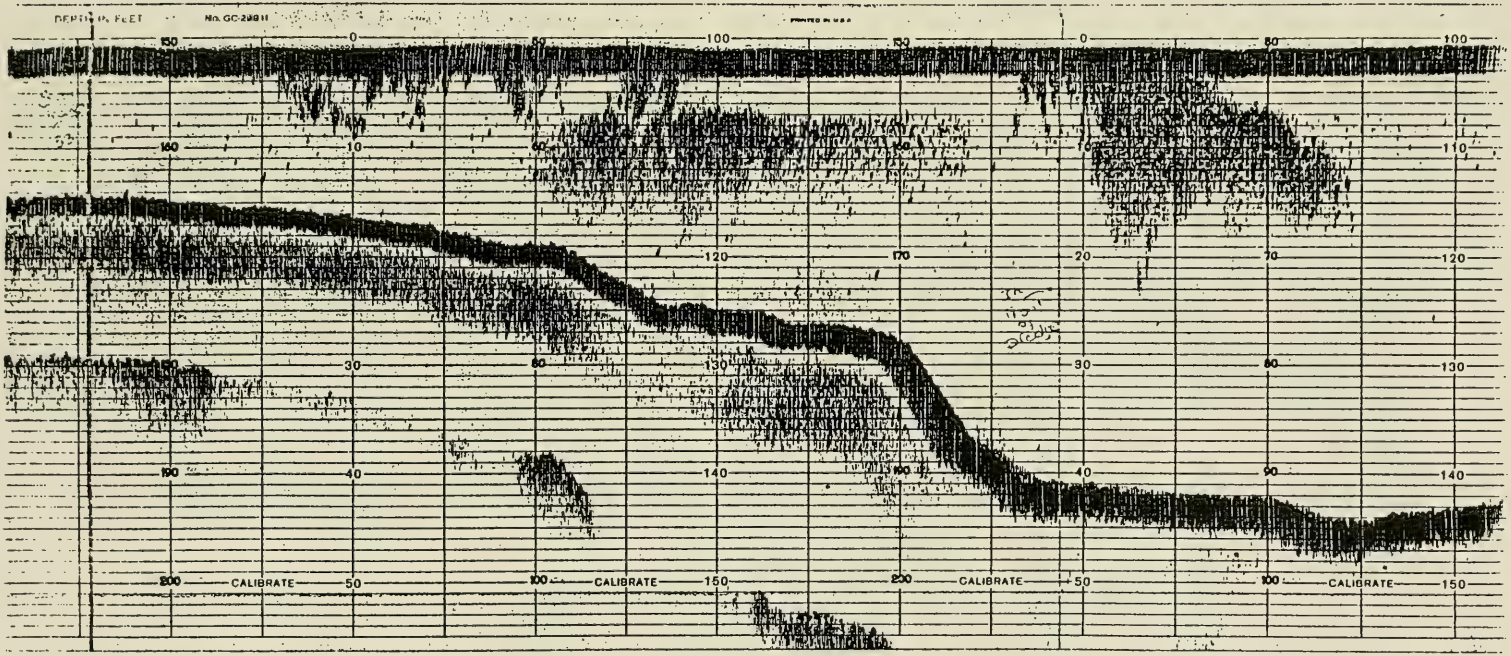
End segment of Transect #49 acoustic survey of 18 November 1993; profile runs west to east



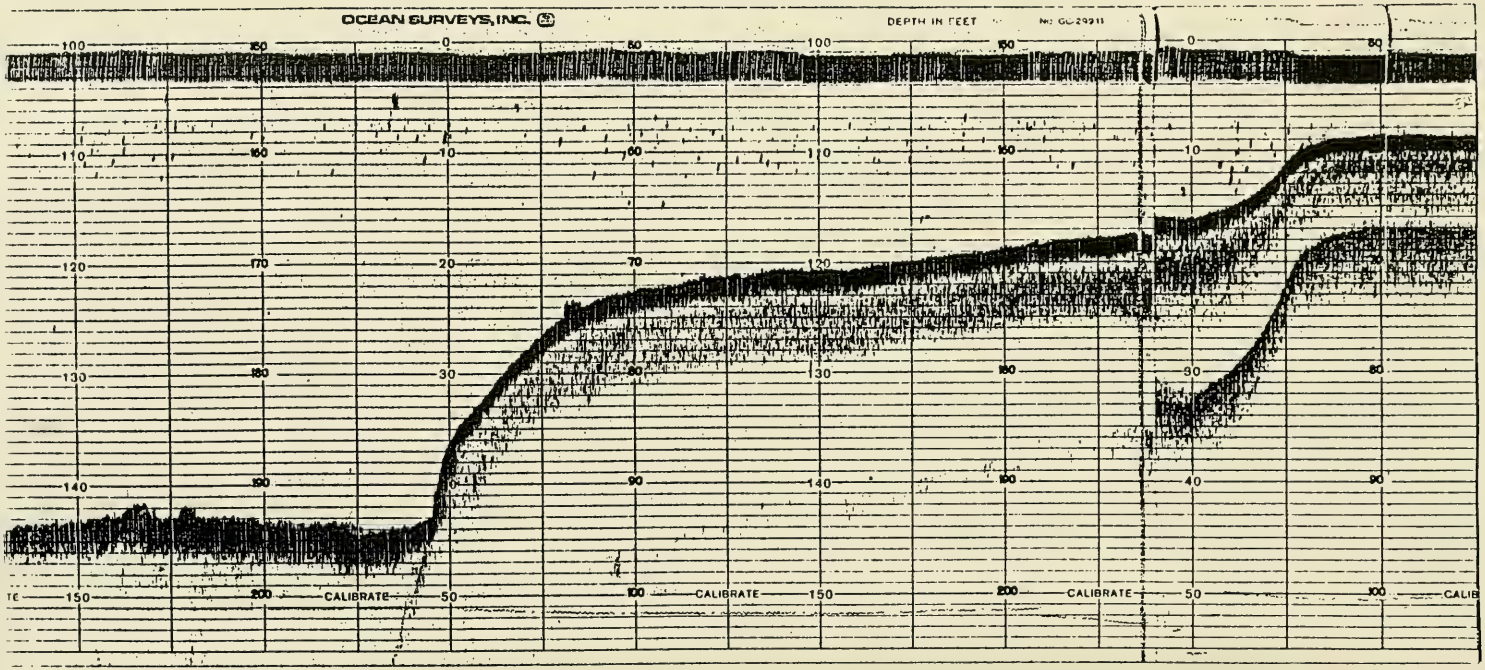
Beginning segment of Transect #50 acoustic survey of 18 November 1993; profile runs east to west



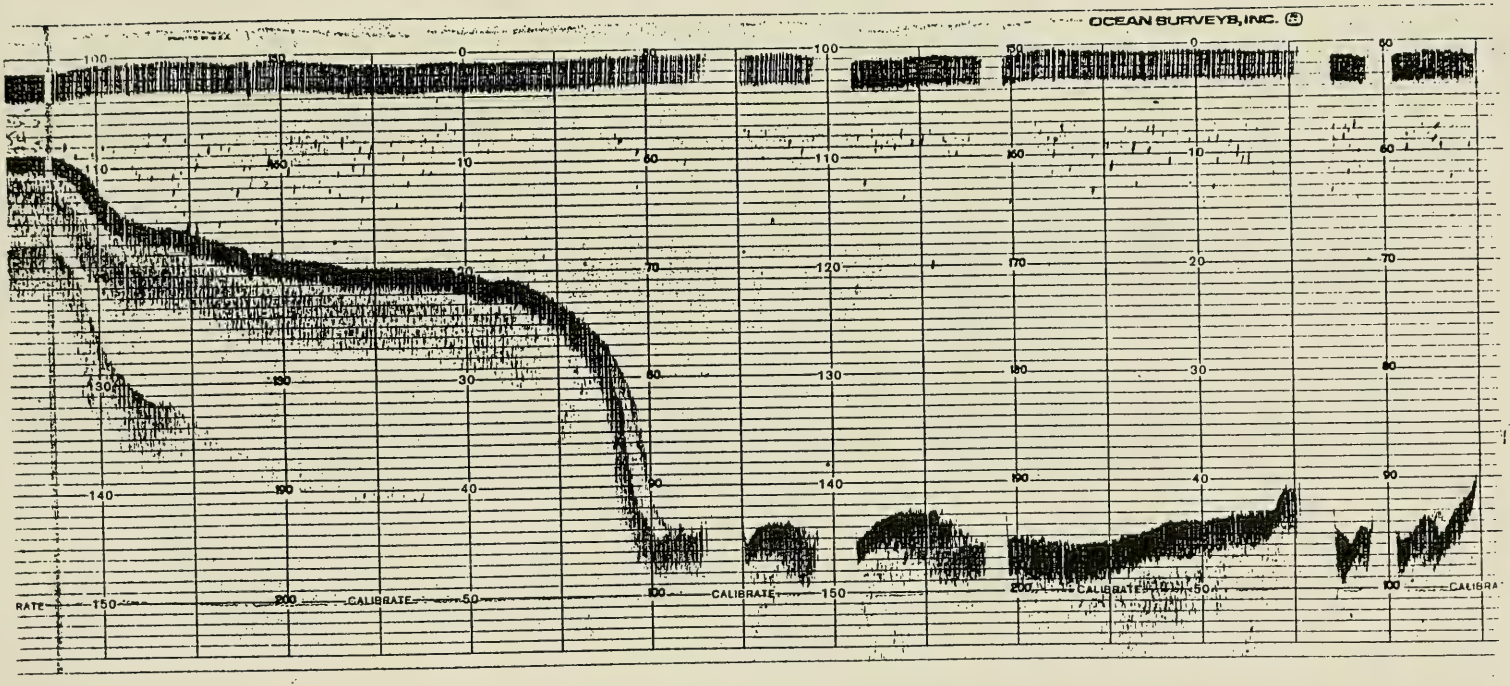
End segment of Transect #50 acoustic survey of 18 November 1993; profile runs east to west



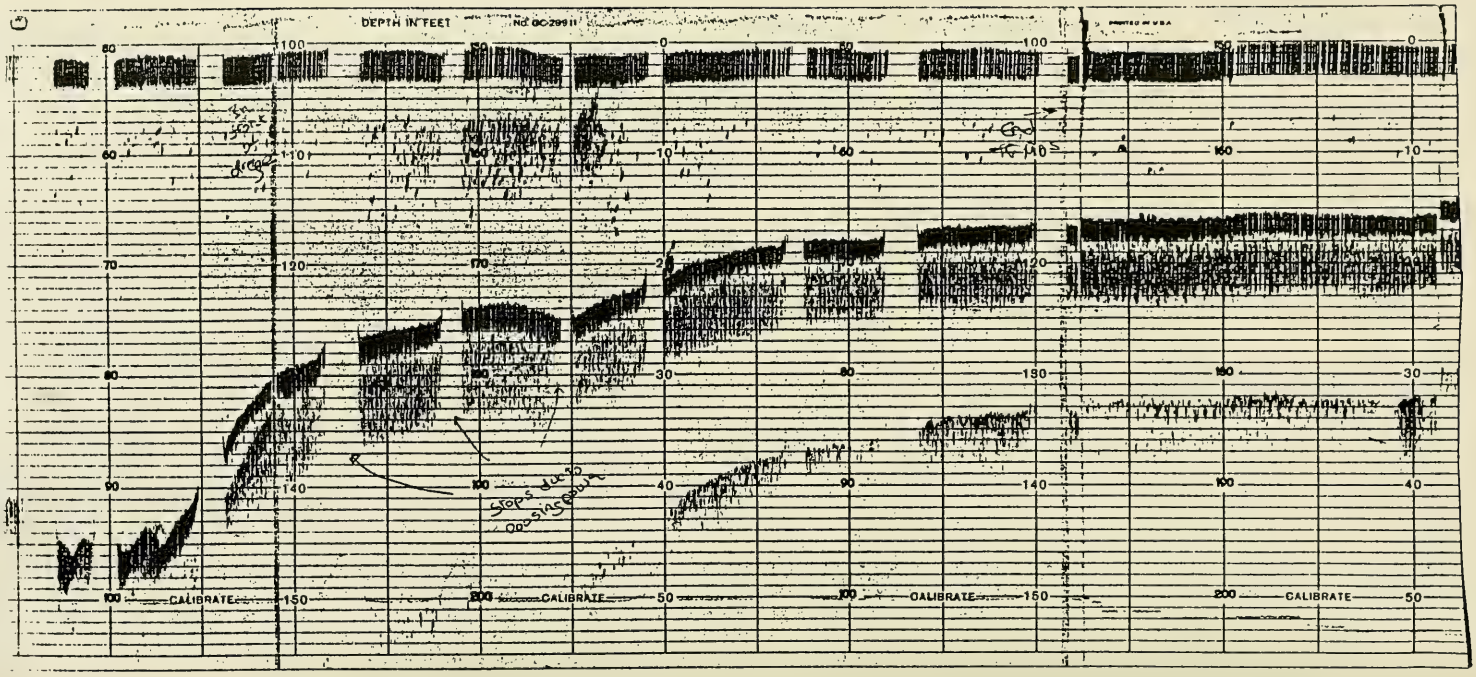
Beginning segment of Transect #53 acoustic survey of 18 November 1993; profile runs west to east



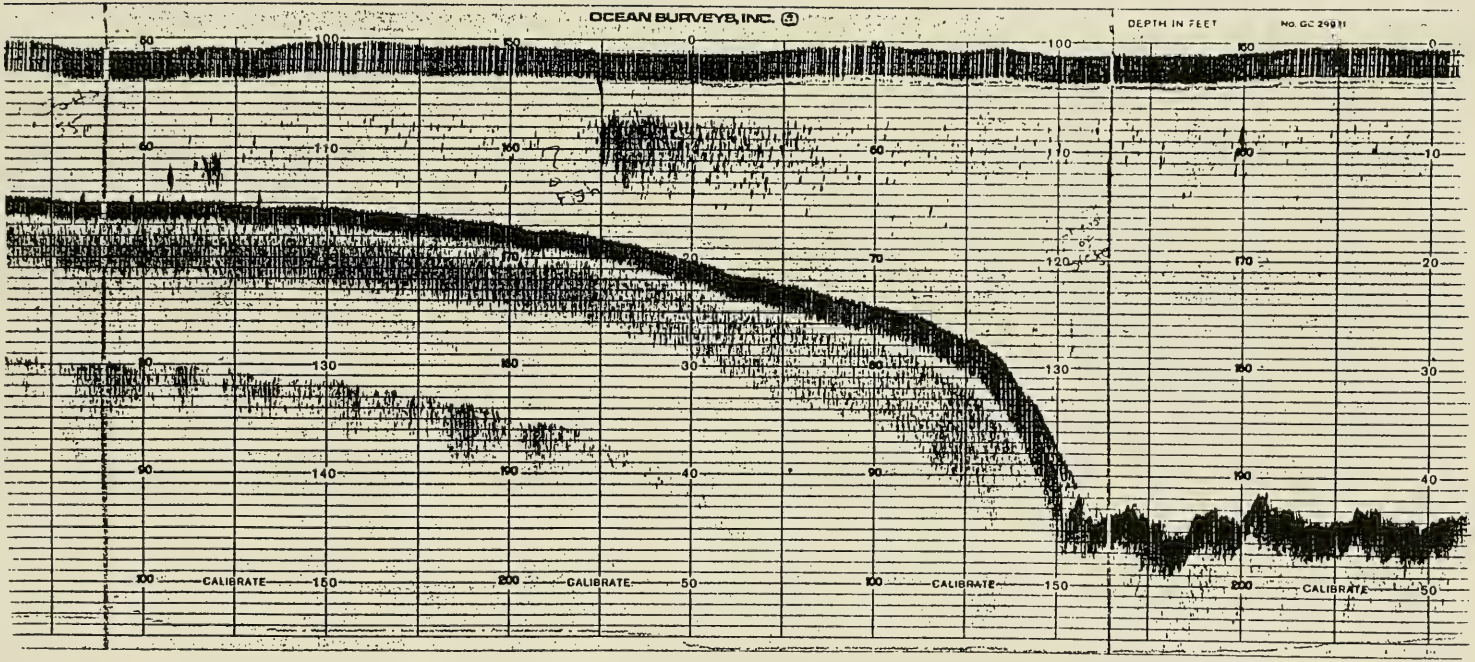
End segment of Transect #53 acoustic survey of 18 November 1993; profile runs west to east



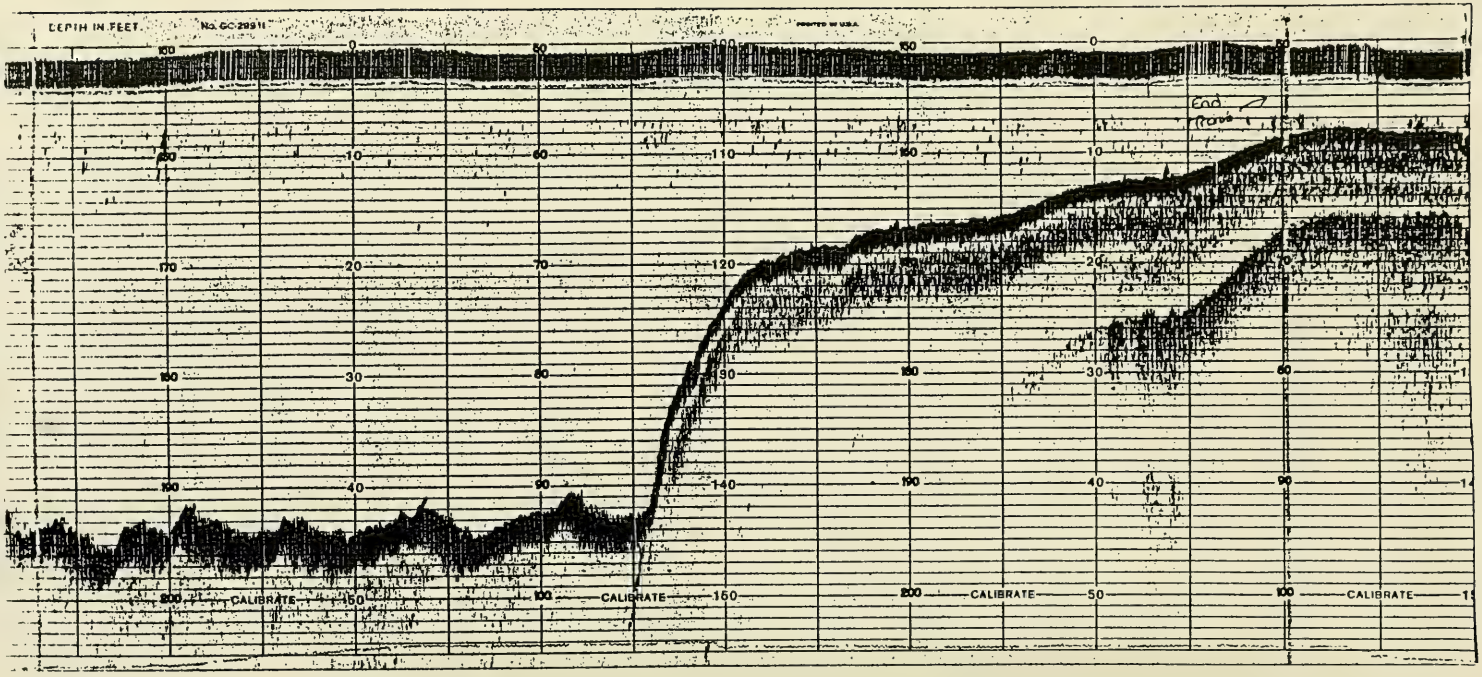
Beginning segment of Transect #54 acoustic survey of 18 November 1993; profile runs east to west



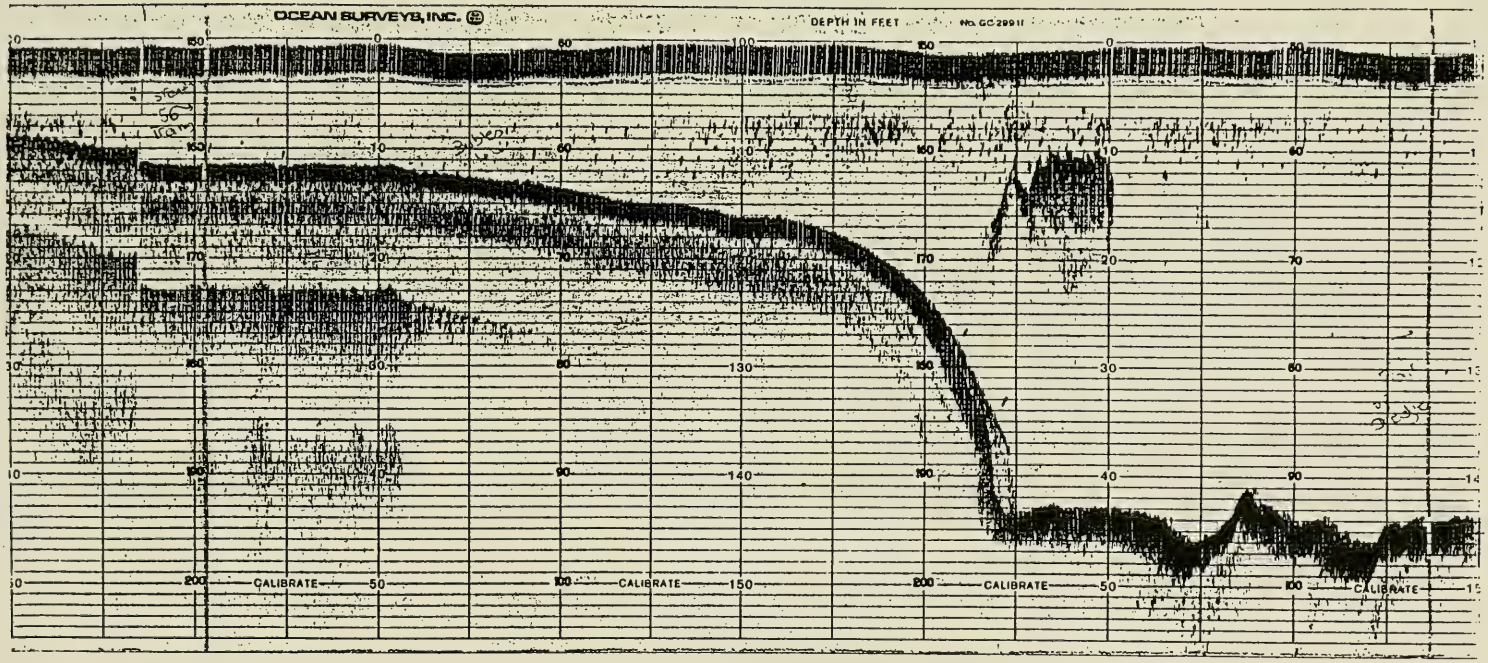
End segment of Transect #54 acoustic survey of 18 November 1993; profile runs east to west



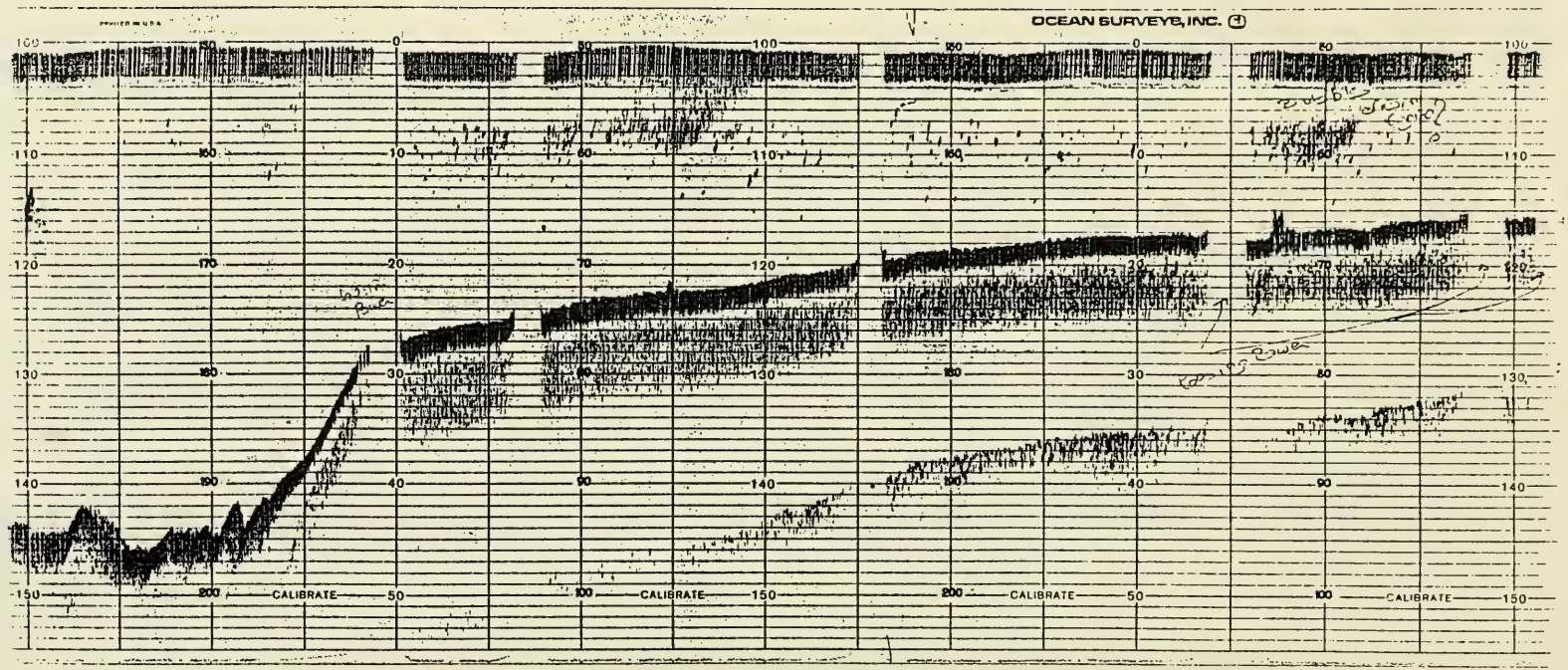
Beginning segment of Transect #55 acoustic survey of 18 November 1993; profile runs west to east



End segment of Transect #55 acoustic survey of 18 November 1993; profile runs west to east



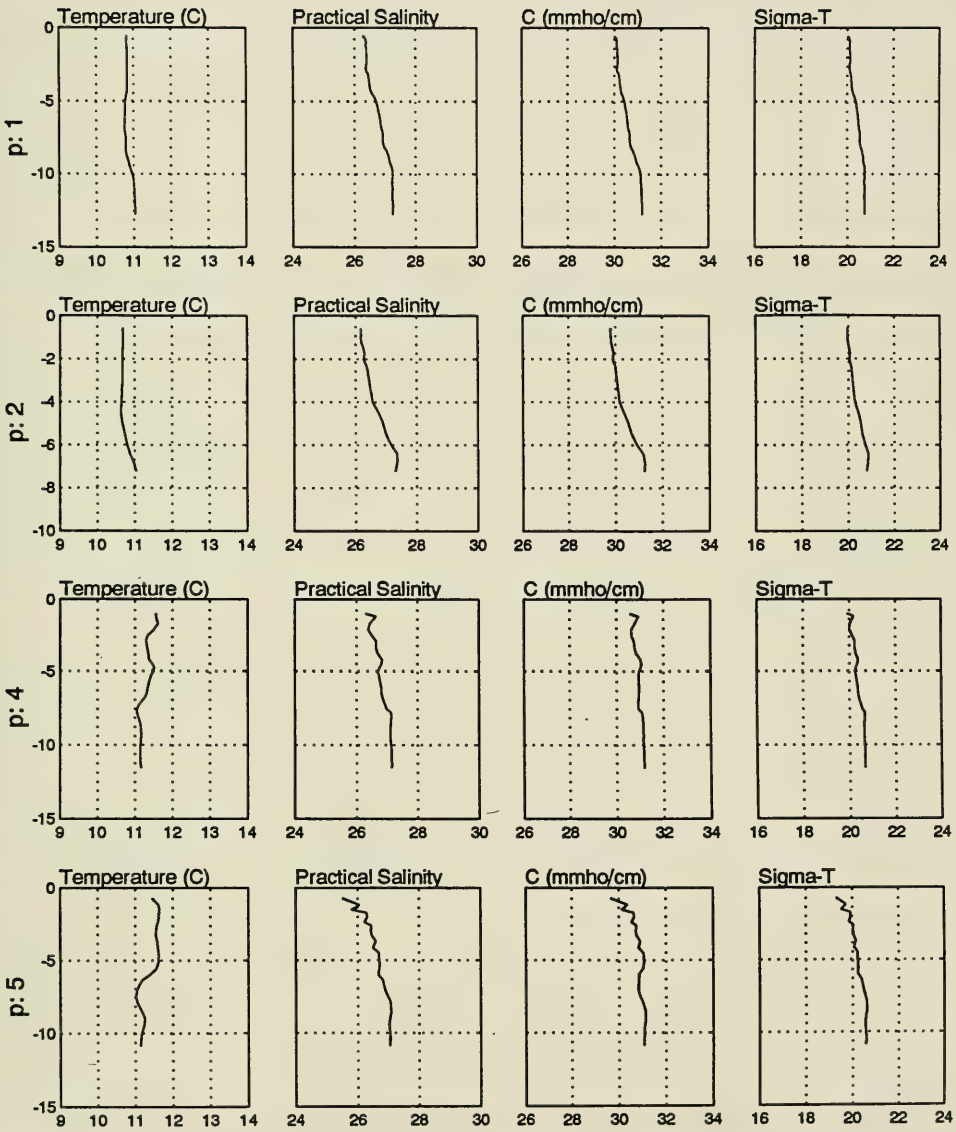
Beginning segment of Transect #56 acoustic survey of 18 November 1993; profile runs east to west

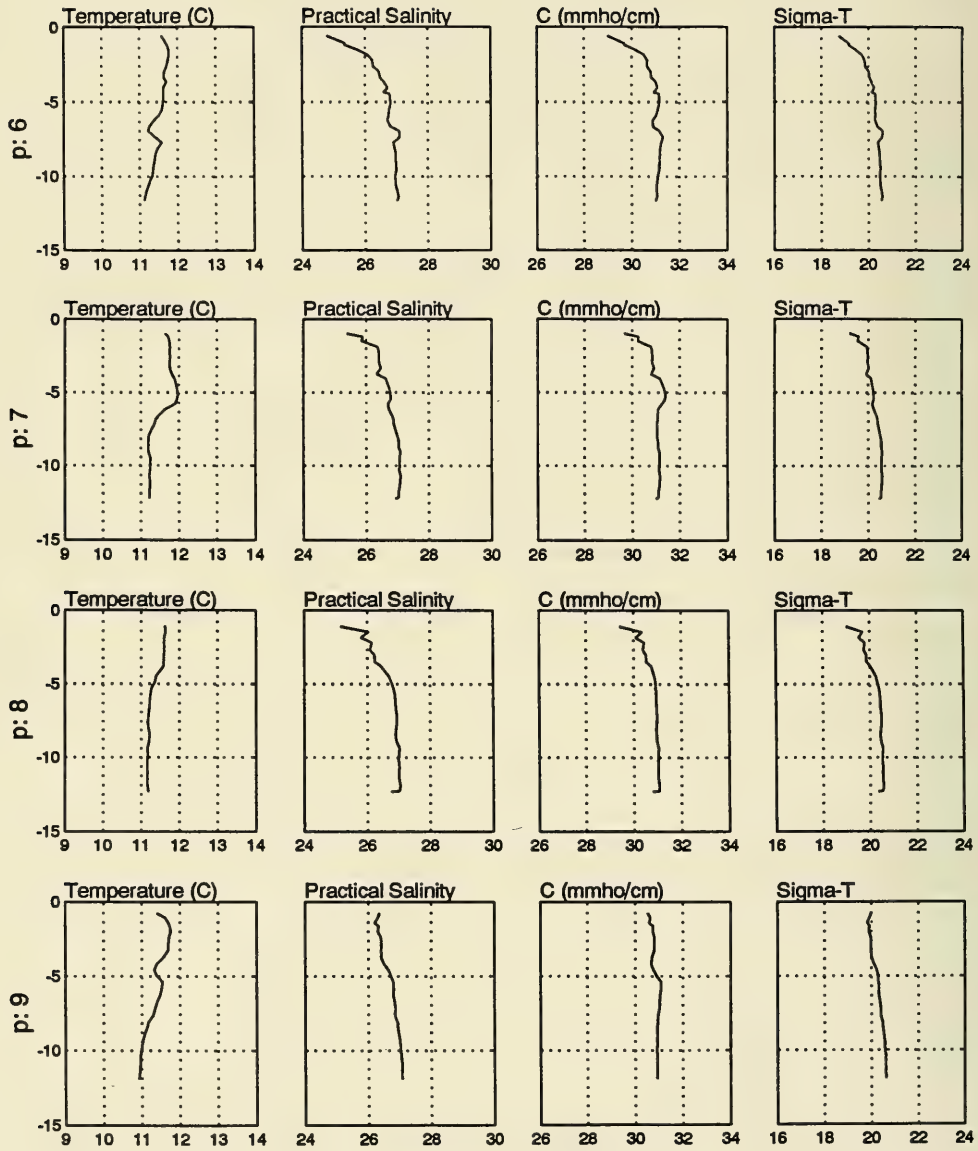


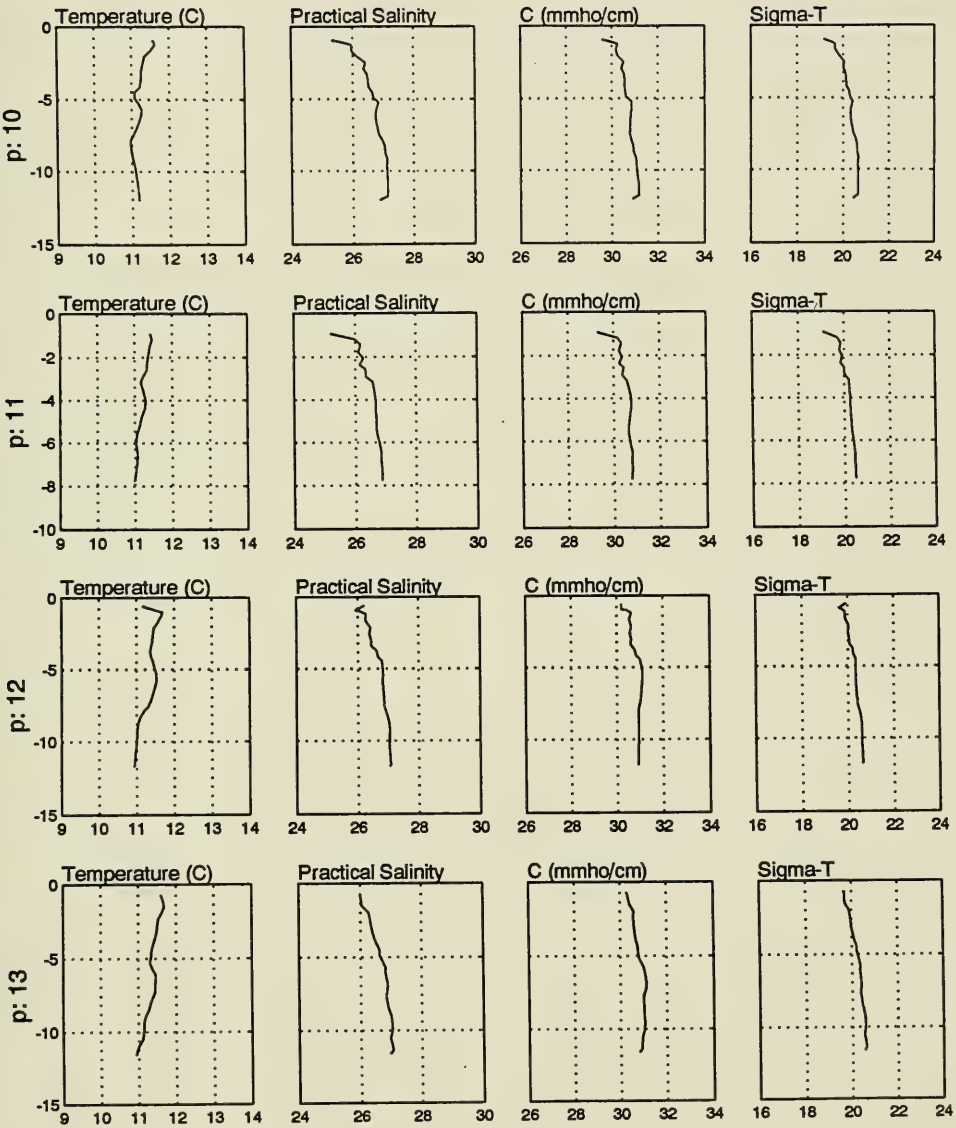
End segment of Transect #56 acoustic survey of 18 November 1993; profile runs east to west

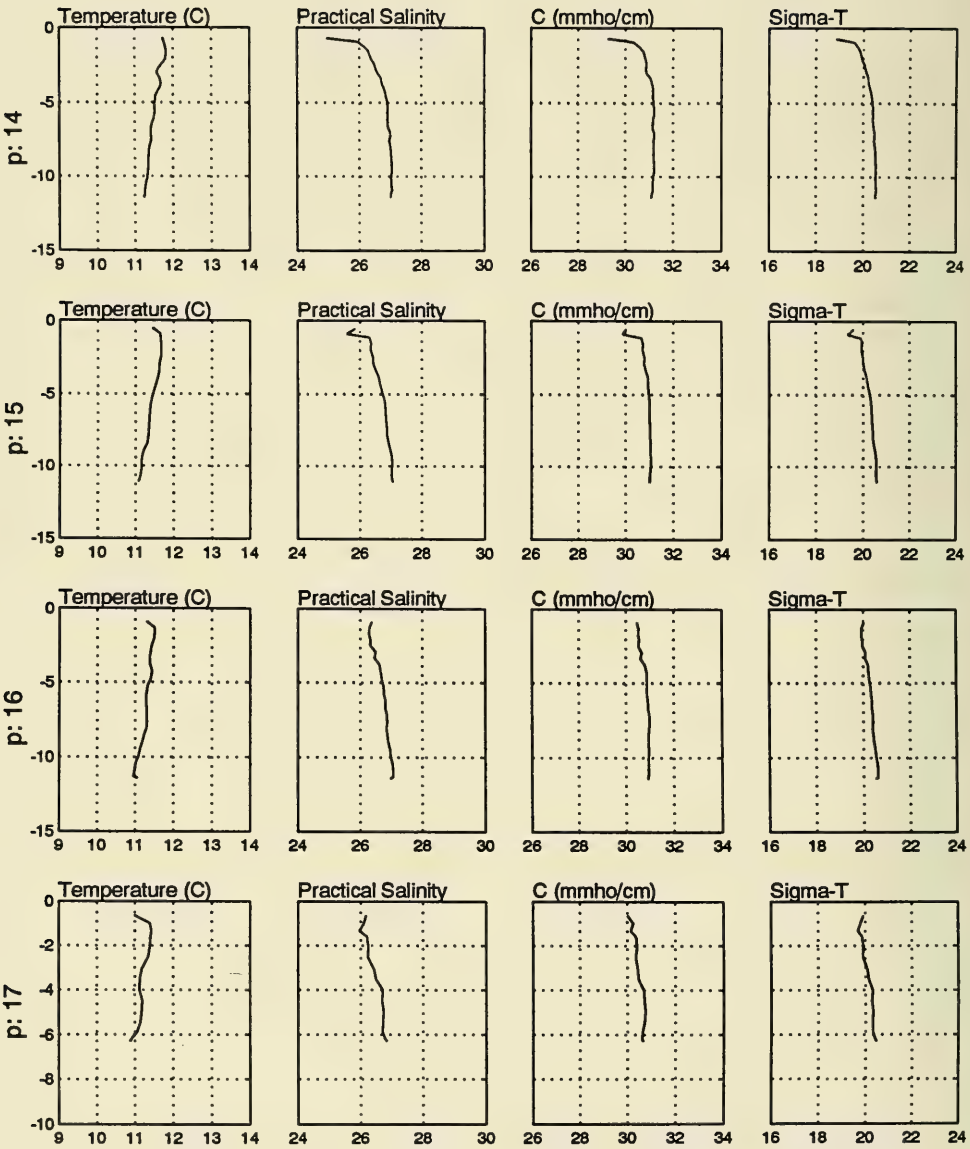
APPENDIX II

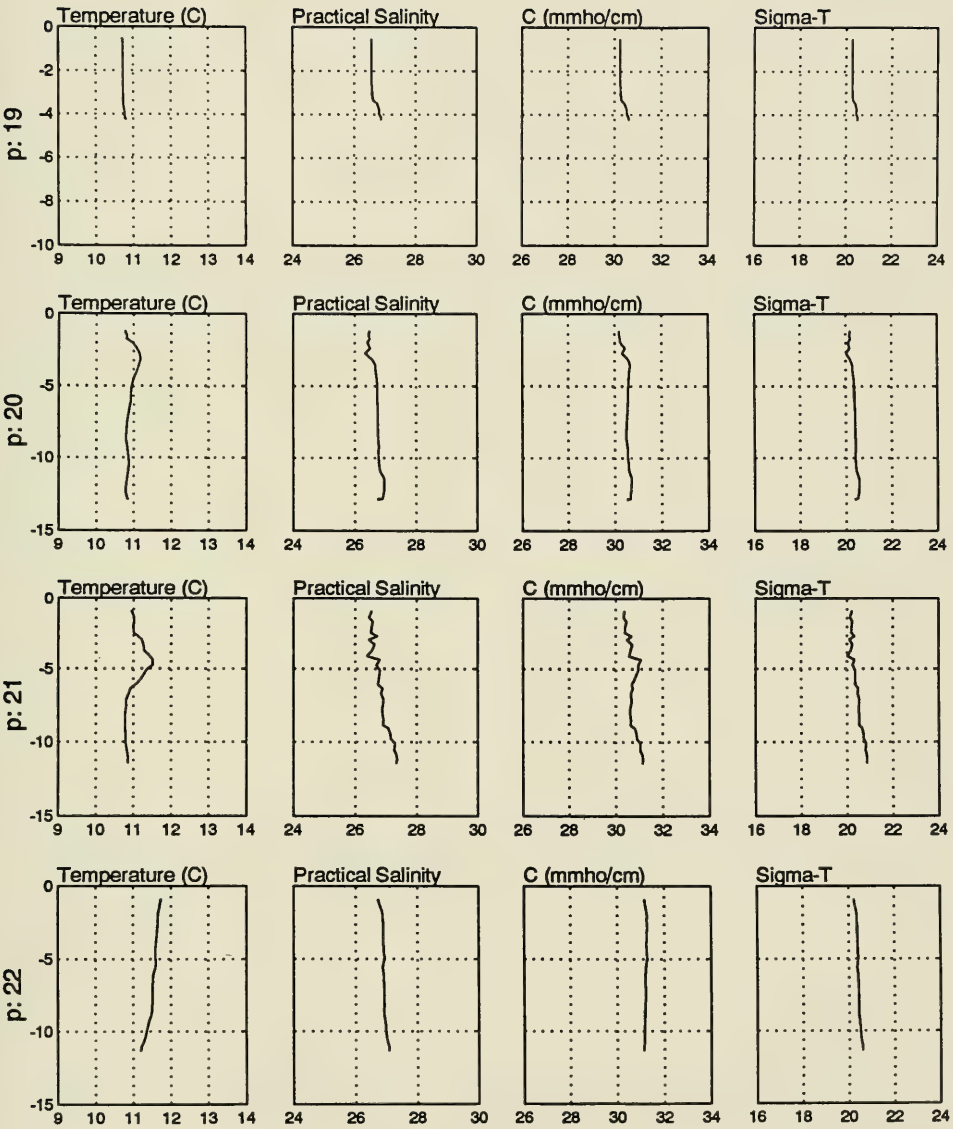
CTD PROFILES

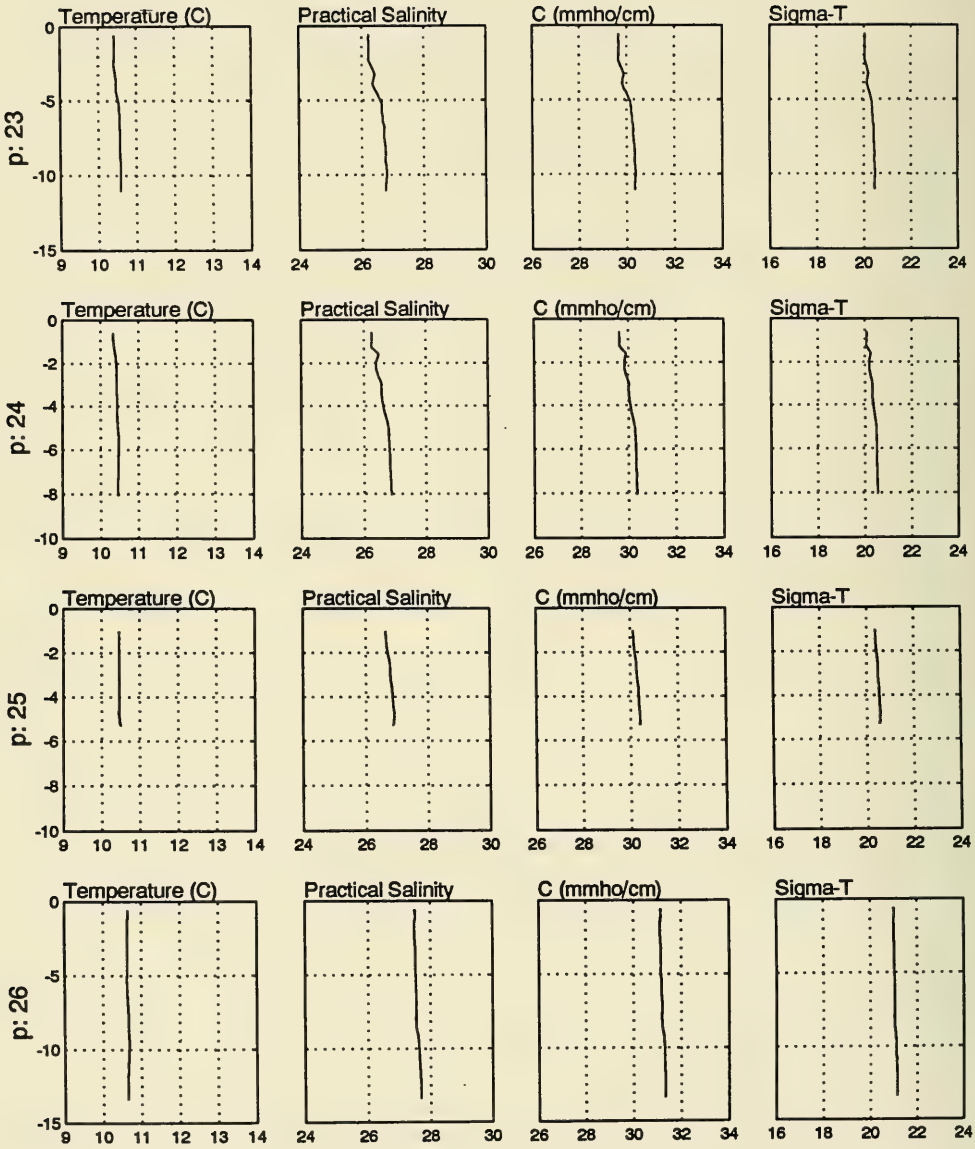

Temperature (C)
Practical Salinity
C (mmho/cm)
Sigma-T
p: 1
p: 2
p: 4
p: 5

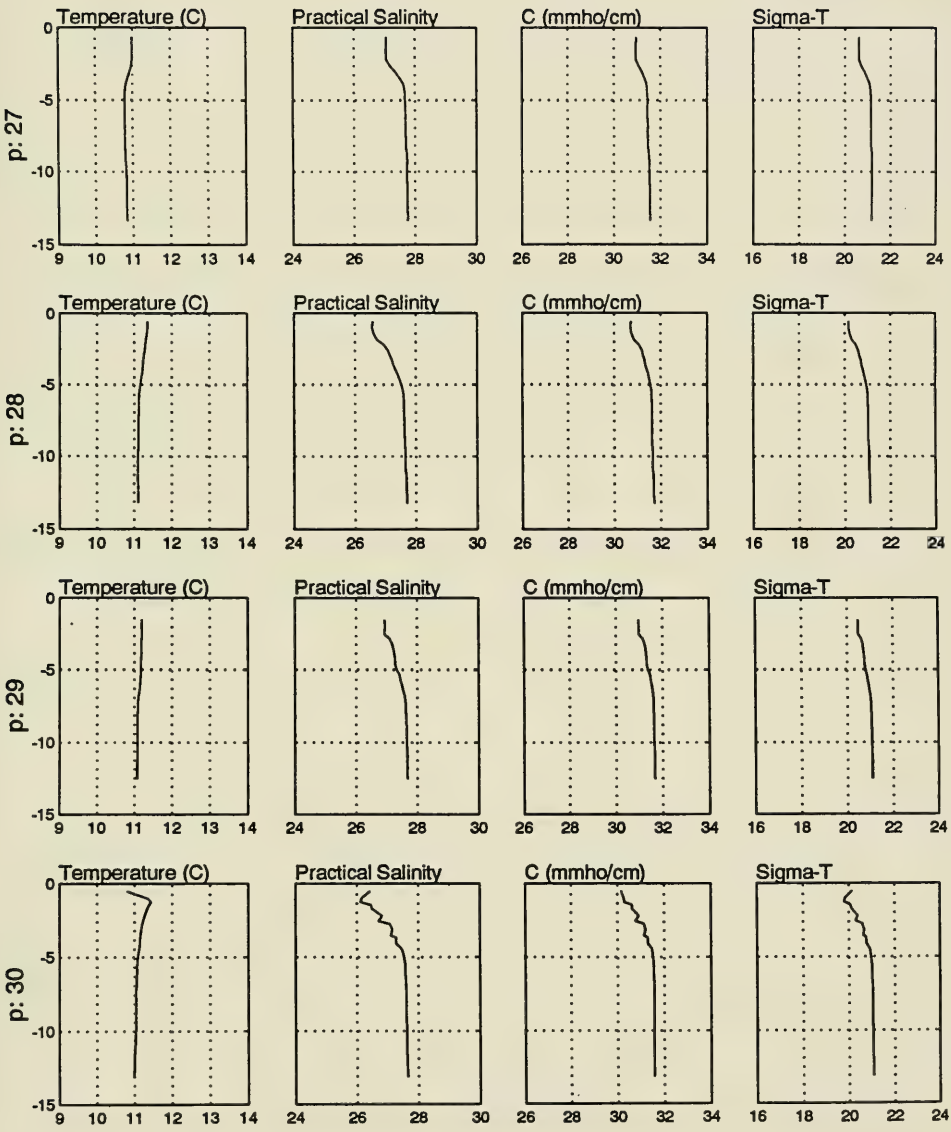

p: 6
Temperature (C)
Practical Salinity
C (mmho/cm)
Sigma-T
p: 7
Temperature (C)
Practical Salinity
C (mmho/cm)
Sigma-T
p: 8
Temperature (C)
Practical Salinity
C (mmho/cm)
Sigma-T
p: 9
Temperature (C)
Practical Salinity
C (mmho/cm)
Sigma-T

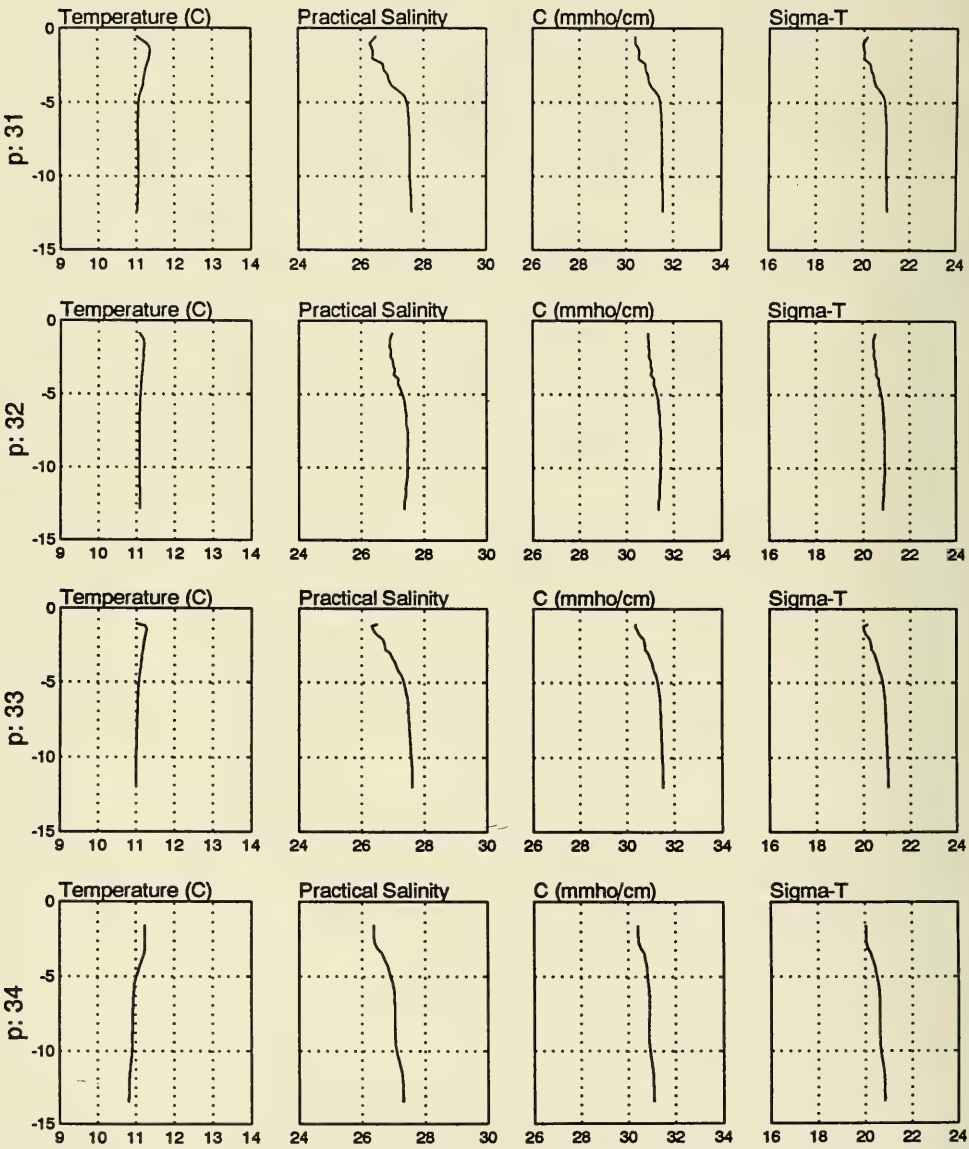

p: 10
Temperature (C)
Practical Salinity
C (mmho/cm)
Sigma-T
p: 11
Temperature (C)
Practical Salinity
C (mmho/cm)
Sigma-T
p: 12
Temperature (C)
Practical Salinity
C (mmho/cm)
Sigma-T
p: 13
Temperature (C)
Practical Salinity
C (mmho/cm)
Sigma-T

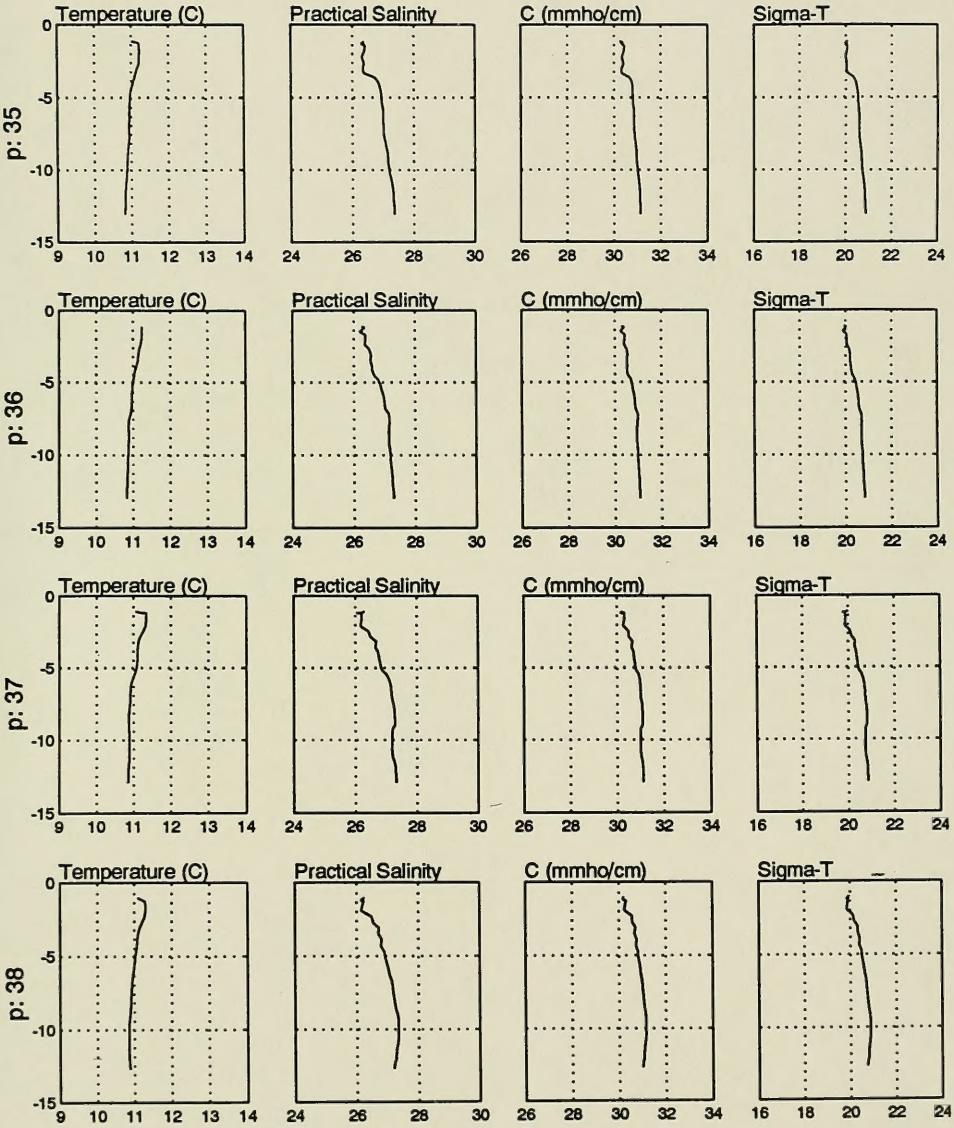

p: 14
Temperature (C)
Practical Salinity
C (mmho/cm)
Sigma-T
p: 15
Temperature (C)
Practical Salinity
C (mmho/cm)
Sigma-T
p: 16
Temperature (C)
Practical Salinity
C (mmho/cm)
Sigma-T
p: 17
Temperature (C)
Practical Salinity
C (mmho/cm)
Sigma-T

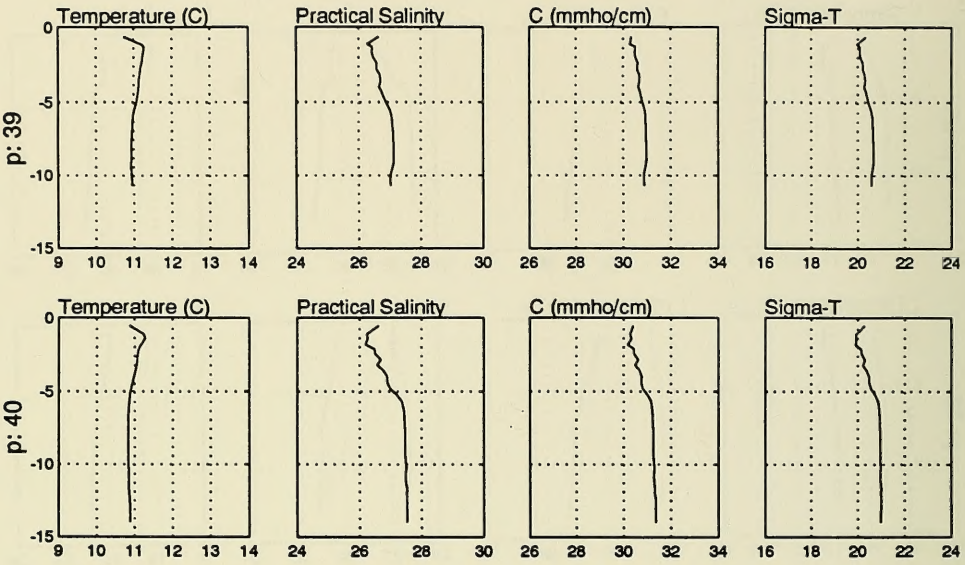

p: 19
Temperature (C)
Practical Salinity
C (mmho/cm)
Sigma-T
0
-2
-4
-6
-8
-10
9 10 11 12 13 14
24 26 28 30
26 28 30 32 34
16 18 20 22 24
p: 20
Temperature (C)
Practical Salinity
C (mmho/cm)
Sigma-T
0
-5
-10
-15
9 10 11 12 13 14
24 26 28 30
26 28 30 32 34
16 18 20 22 24
p: 21
Temperature (C)
Practical Salinity
C (mmho/cm)
Sigma-T
0
-5
-10
-15
9 10 11 12 13 14
24 26 28 30
26 28 30 32 34
16 18 20 22 24
p: 22
Temperature (C)
Practical Salinity
C (mmho/cm)
Sigma-T
0
-5
-10
-15
9 10 11 12 13 14
24 26 28 30
26 28 30 32 34
16 18 20 22 24


p: 23
Temperature (C)
Practical Salinity
C (mmho/cm)
Sigma-T
0
-5
-10
-15
9 10 11 12 13 14
24 26 28 30
26 28 30 32 34
16 18 20 22 24
p: 24
Temperature (C)
Practical Salinity
C (mmho/cm)
Sigma-T
0
-2
-4
-6
-8
-10
9 10 11 12 13 14
24 26 28 30
26 28 30 32 34
16 18 20 22 24
p: 25
Temperature (C)
Practical Salinity
C (mmho/cm)
Sigma-T
0
-2
-4
-6
-8
-10
9 10 11 12 13 14
24 26 28 30
26 28 30 32 34
16 18 20 22 24
p: 26
Temperature (C)
Practical Salinity
C (mmho/cm)
Sigma-T
0
-5
-10
-15
9 10 11 12 13 14
24 26 28 30
26 28 30 32 34
16 18 20 22 24


Temperature (C)
Practical Salinity
C (mmho/cm)
Sigma-T
p: 27
p: 28
p: 29
p: 30
0
-5
-10
-15
9 10 11 12 13 14
24 26 28 30
26 28 30 32 34
16 18 20 22 24


p: 31
p: 32
p: 33
p: 34
Temperature (C)
Practical Salinity
C (mmho/cm)
Sigma-T
0
-5
-10
-15
9 10 11 12 13 14
24 26 28 30
26 28 30 32 34
16 18 20 22 24


Temperature (C)
Practical Salinity
C (mmho/cm)
Sigma-T
p: 35
p: 36
p: 37
p: 38
0
-5
-10
-15
9 10 11 12 13 14
24 26 28 30
26 28 30 32 34
16 18 20 22 24


Temperature (C)
Practical Salinity
C (mmho/cm)
Sigma-T
p: 39
p: 40
0
-5
-10
-15
9 10 11 12 13 14
24 26 28 30
26 28 30 32 34
16 18 20 22 24